

**Professional Guide Series:**

**REDUCING THE VULNERABILITY  
OF HOUSES**

**DEPARTMENT OF DEFENSE  
OFFICE OF CIVIL DEFENSE  
WASHINGTON 25, D.C.**

## PREFACE

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This Professional Guide is one of a series of technical publications prepared under the direction of the Protective Structures Division of Civil Defense. The purpose of the Office of Civil Defense Technical Publications is to provide information and guidance to the building and design of structures that contain protective features.

This publication was prepared for the Department of Defense, Office of Civil Defense, by the Small Homes Council - Building Research Council of the University of Illinois, Rudard A. Jones, Director; Brian J. Crumlish, Professional Guide Series: Author. Members of the staff of the Small Homes Council - Building Research Council, along with certain members of the University of Illinois Departments of Architecture and Civil Engineering, assisted in the investigation.

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The architect or the engineer and his client will have to decide the extent of protective measures to be taken. This decision will be influenced by the location of the residence with respect to probable targets.

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Better utilization of inherent resistance results from good planning of the structure and the site. Additional expense required in most cases is nominal.

## INTRODUCTION

Because the principal targets of a nuclear attack could be metropolitan areas or areas surrounded by mass housing, the vulnerability of the residential structure to the effects of nuclear weapons should be reduced. This could result in a reduction in the number of houses destroyed and ease the burden of rehousing the population following an attack.

The architect or the engineer and his client will have to decide the extent of protective measures to be taken. This decision will be influenced by the location of the residence with respect to probable targets and the additional investment that the owner wishes to make.

Although total blast, thermal, and radiation protection is economically impractical, it should be kept in mind that with each protective measure taken, the probability of destruction is effectively decreased.

Added strength will have other compensations in the form of greater resistance to such natural hazards as hurricanes, tornadoes, and earthquakes. Simple methods and devices used to provide protection from thermal radiation will lessen the vulnerability of the house to other fire dangers. Fallout shelters can be incorporated within the residence or reliance can be placed on available community shelters.

Better utilization of inherent resistance results from good planning of the structure and the site. Additional expense required in most cases is nominal.

Further variations result from a change in the height of burst above the ground. Fallout in large quantities will only result from the contact of the fireball with the surface of the earth, while thermal and blast effects at a given distance will increase with the burst height up to a certain altitude. Atmospheric conditions, varying continuously, present another incalculable factor. For example, direction and speed of high altitude winds varies the distribution pattern of fallout; atmosphere with limited visibility attenuates or weakens a thermal wave. The relationship of the house to an explosion, the distance, and intervening terrain further increase or decrease certain effects.



## CHAPTER I

### NUCLEAR EFFECTS AND RESIDENTIAL CONSTRUCTION

#### 1-1 General

In the design of a residence to conventional standards, building codes and good practice have established minimum design standards which a structure must meet to be considered safe. When designing to resist the effects of a nuclear explosion, relatively limited test data is available. An exact design basis for these new forces is difficult to establish. In the area of residential construction, it is recommended that the designer examine the residence as a whole and modify its most vulnerable details rather than attempt to establish exact values on which to base the resistance of the house. Obvious fire hazards should be eliminated, weak structural parts strengthened, and inherent radiation barriers better utilized to provide a higher degree of resistance and protection.

Ideally, a balance of resistance to all hazards should be attained, but for this one must assume a specific bomb size, an exact position of the house relative to the detonation, and certain climatic conditions. Any variation could subject the house to an increase in certain nuclear effects and a decrease in others, as the intensity of each effect varies independently. The complexity of combining these variables results in an almost infinite pattern of design criteria.

Examination of some of the elements influencing the nuclear effects points out the wide variations that may be expected. First, the most obvious variation results from the size of the weapon exploded. Both blast pressures and gamma radiation hazards increase with the magnitude of the yield, as does the total heat emitted; but the duration of the thermal pulse increases with the yield, diminishing the hazardous effect of thermal radiation.

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Approximately one-half of the energy released from a thermonuclear explosion is in the form of blast or pressure energy, one-third is in the form of thermal energy, and the remainder in the form of prompt radiation and residual radiation or fallout. In general, it may be said that the fallout will cover the largest area and present the greatest direct hazard to the population. Blast and thermal effects will have limited ranges and present hazards both to buildings and to the population.

Figure 1-1 illustrates an idealized pattern of anticipated dangers from a one megaton surface burst, assuming a 15 mph wind.

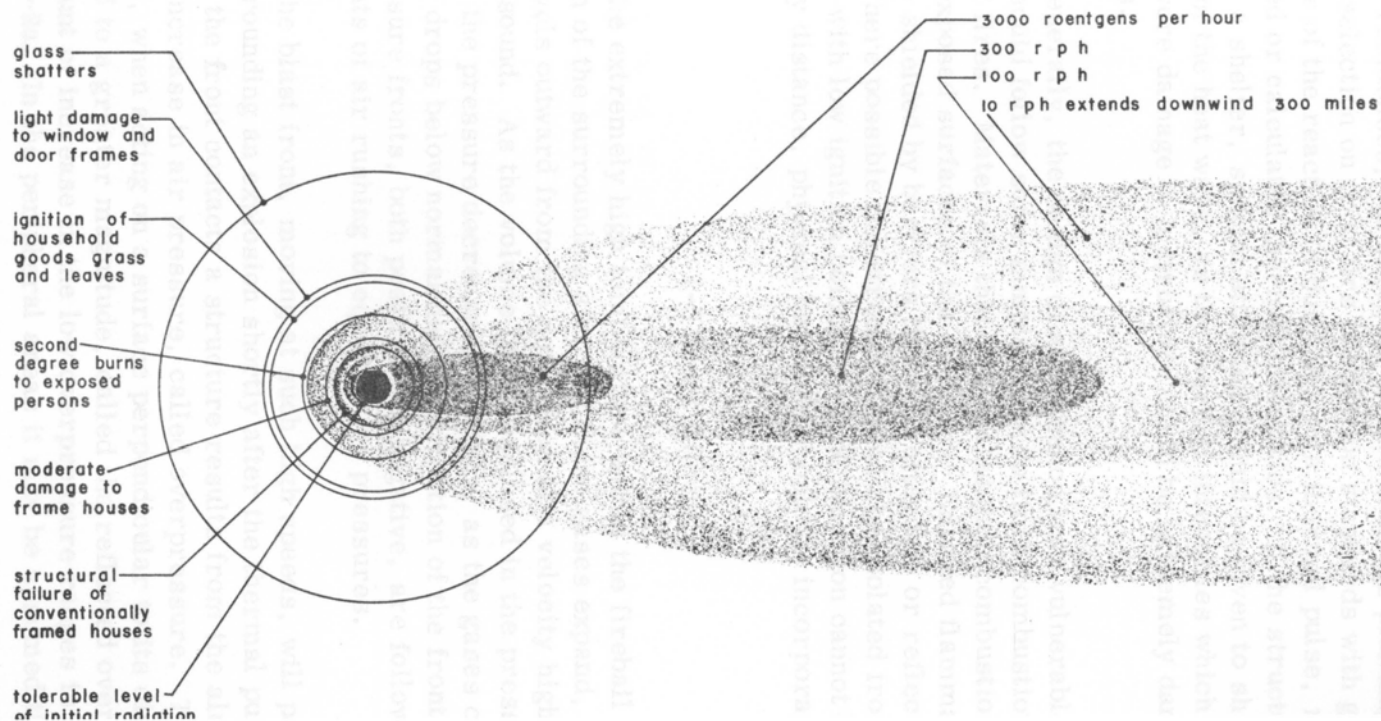
### 1-2 Thermal and Fire Hazard

The thermal energy released from an explosion is in the form of visible light, infrared, and ultraviolet rays. This energy travels outward in a straight line in all directions from the detonation at the speed of light and is the first effect to reach the area surrounding the target.

The amount of this energy received, the time period over which the energy is applied, and the ignition point of the material receiving the energy will determine the probability of fires. The measurement of total heat is a direct function of the bomb yield, and the total energy received on a given area diminishes inversely with the square of the distance between the area and the point of burst. The duration of the thermal pulse increases with the magnitude of the yield. Therefore, more total heat, measured in calories per square centimeter, will be required to ignite a material from a megaton explosion than would be required from a lower yield weapon.

The ignition point of the material is dependent upon such physical characteristics as moisture content, temperature difference, thickness, and color. Paper, trash, grass, dry leaves, and window curtains have low ignition points. Wood exposed to thermal radiation usually exhibits only transient burning but will be charred to a depth closely proportional to the energy received.

In the fringe areas, where it is expected that strengthened houses will withstand the subsequent blast wave, the thermal intensities received as a direct result of the thermal pulse will not be sufficient to cause ignition of well-maintained structures. The chief fire danger results from the ignition of more flammable materials in the yards or the interiors of the houses, and from the spread of these fires to the structure. In addition, the danger of fires as an indirect effect of the



destruction of the blast wave should be considered. Upset stoves and furnaces, electrical short circuits, and broken gas lines may start fires within a structure that might otherwise be isolated from flammable material.

Since direct exposure to a thermal pulse is not the chief fire danger to residences, the designer should base his planning and material selection on good fire prevention standards with general knowledge of the reaction of buildings to a thermal pulse, rather than on anticipated or calculated thermal intensities. If the structure is intended as a shelter, special attention should be given to shield the occupants from the heat wave, as the thermal intensities which might not cause severe damage to a structure could be extremely dangerous to the occupants.

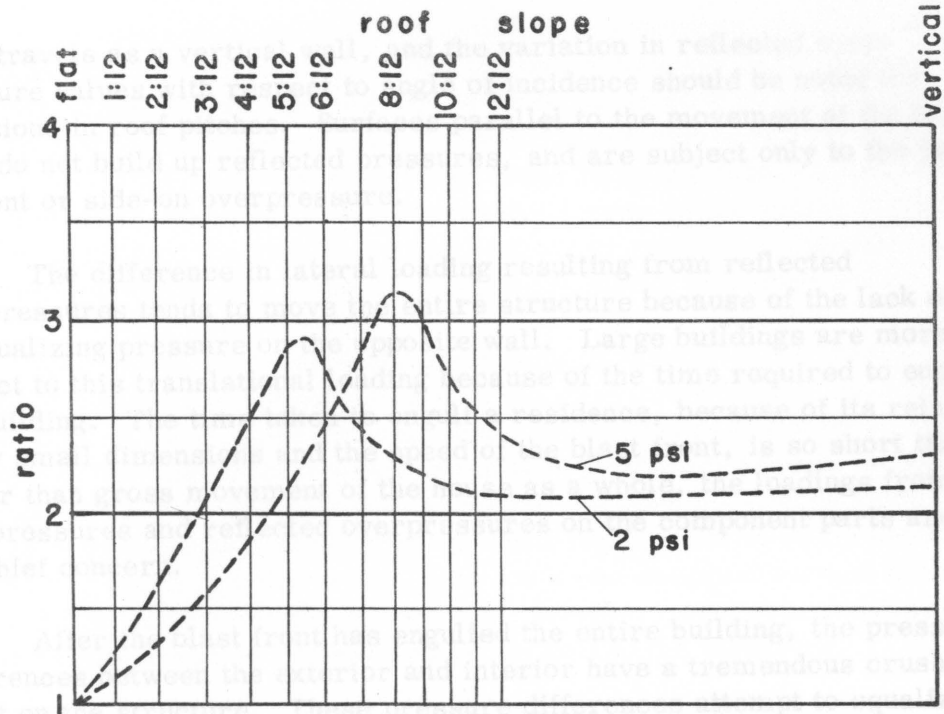
Generally, the design of a residence less vulnerable to thermal effects should follow some simple rules to limit combustion and the spread of fires. Materials that will not sustain combustion should be used on exposed surfaces of the exterior. Exposed flammable materials should be shielded by barriers that will attenuate or reflect the thermal wave. Where possible the structure should be isolated from other elements with low ignition points. Where isolation cannot be accomplished by distance, physical barriers should be incorporated in the design.

### 1-3 Blast Effects

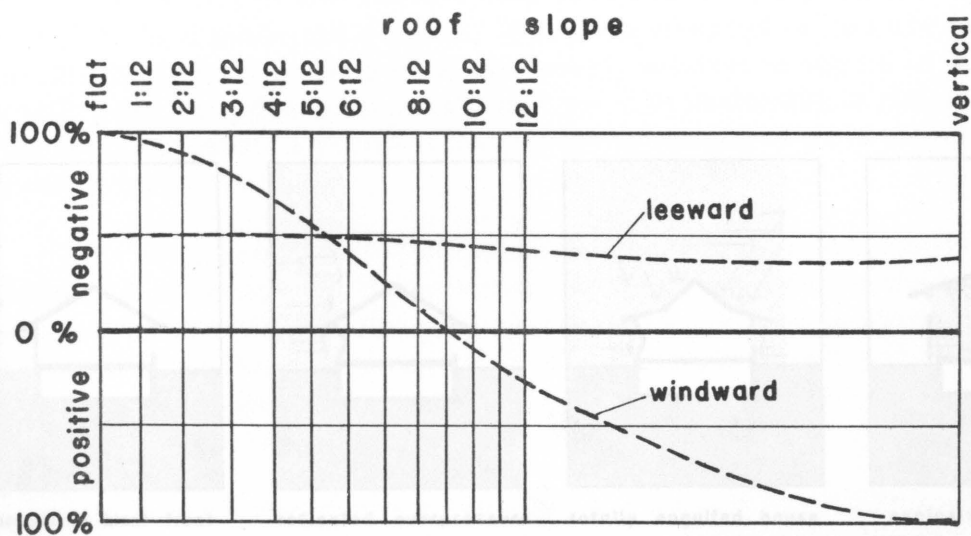
The extremely high temperature within the fireball causes a rapid expansion of the surrounding air. As these gases expand, a pressure front travels outward from the detonation at a velocity higher than the speed of sound. As the volume of air enclosed in the pressure front increases, the pressure decreases, and then, as the gases cool, the pressure drops below normal and the direction of the front reverses. The pressure fronts, both positive and negative, are followed by rapid movements of air rushing to equalize the pressures.

The blast front, moving at such high speeds, will pass through the area surrounding an explosion shortly after the thermal pulse. The first effect as the front contacts a structure results from the almost instantaneous increase in air pressure, called overpressure. This overpressure, when acting on a surface perpendicular to its direction, is amplified to a greater magnitude, called the reflected overpressure. The amount of increase in the low overpressure ranges is shown in Figure 1-2a. In the peripheral areas it may be assumed that the blast





(a) ratio of reflected overpressure with respect to roof slope to side-on overpressure



(b) percentage of positive and negative wind pressure with respect to roof slope

figure 1-2 effects of slope on overpressure and wind forces

front travels as a vertical wall, and the variation in reflected overpressure values with respect to angle of incidence should be noted for variations in roof pitches. Surfaces parallel to the movement of the blast front do not build up reflected pressures, and are subject only to the peak incident or side-on overpressure.

The difference in lateral loading resulting from reflected overpressures tends to move the entire structure because of the lack of an equalizing pressure on the opposite wall. Large buildings are more subject to this translational loading because of the time required to engulf the building. The time taken to engulf a residence, because of its relatively small dimensions and the speed of the blast front, is so short that, rather than gross movement of the house as a whole, the loadings from overpressures and reflected overpressures on the component parts are the chief concern.

After the blast front has engulfed the entire building, the pressure differences between the exterior and interior have a tremendous crushing effect on the structure. These pressure differences attempt to equalize through the various openings and cracks in the building, and, as the blast front moves onward, the pressure may build up within the structure to a level higher than the outside pressure. The structure would then be subject to an exploding force. See Figure 1-3.

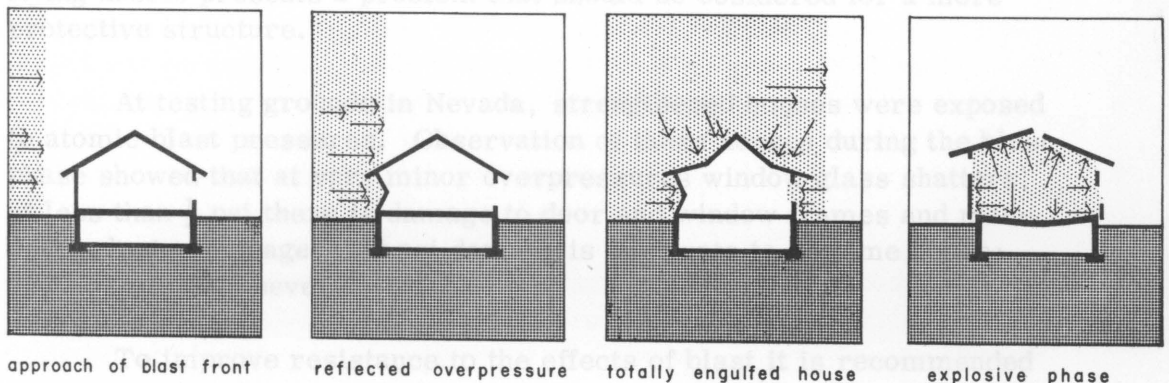


figure 1-3 blast effects on a house



The subsequent dynamic or drag forces caused by the rushing of air behind the pressure front, unlike the overpressures, act only in the direction of their path. The effects of these winds on a structure are similar to those experienced in a tornado. In the overpressure range between 2 and 5 psi, the velocities range from 70 to 160 mph. These lateral forces may induce uplift or compressive forces on the roofs, translation or rotation of the structure, and bending or racking of the walls. Pressure variation with angle of incidence is shown in Figure 1-2b.

The radius of the structurally damaging effects of the blast wave traveling through the air extends as far as 20 or more miles, depending on the yield of the nuclear device. Some of the energy of the explosion appears in the form of a stress wave in the earth which travels outward from ground zero. The resulting earth motion does not create much damage to aboveground structures beyond a range equal to twice the crater radius, which is under a half-mile for a one-megaton surface burst. The shock wave traveling in the air will, however, exert some downward pressure which will be transmitted by the soil to the structure.

Some general statements can be made in regard to strengthening a residence to resist blast effects which may serve as broad guides in preliminary design. It should be mentioned, as in the case of thermal radiation, that these principles apply chiefly to the structure and do not necessarily imply blast protection for the inhabitants. At best, structural resistance in residential construction can be developed to resist 5 psi over pressure at moderate expense. Overpressures below this are not generally fatal, but, at these pressure levels, secondary effects of blast are still quite hazardous. At less than 1 psi, the shattering of glass and flying debris presents a problem that should be considered for a more protective structure.

At testing grounds in Nevada, strengthened houses were exposed to atomic blast pressures. Observation of these houses during the blast phase showed that at very minor overpressures window glass shatters; at less than  $\frac{1}{2}$  psi there is damage to door and window frames and moderate plaster damage; at 2 psi damage is moderate to a frame house; and at 3 psi it is severe.

To improve resistance to the effects of blast it is recommended that the weakest structural elements of a residence be strengthened first. Other weak points may be strengthened as the budget permits. With each improvement, the residence becomes more resistant to damage resulting from other types of dynamic loadings.

The structural characteristics influencing the resistance to blast forces include strength and ductility, mass, and the presence of redundant structural elements. Some degree of each is present in current house construction, and it is hoped to use this inherent resistance more efficiently to decrease structural failure.

Basically, strength is the ability of a structural element to resist deformation. In residential construction, blast resistance can be increased by selecting ductile materials for structural parts and by making joints and connections more rigid to reduce deflections. Brittle materials, such as unreinforced masonry or certain panel materials, fail under small deformations, and unless failure is desired, as in the case of pressure relief through windows, ductile materials should be used. Plastic deformation is achieved in masonry and concrete by introducing steel reinforcement.

Further resistance can be achieved through increased mass, which decreases the acceleration of the structure under dynamic loading.

The presence of redundant structural parts adds considerably to the resistance of a house to blast loadings. Bringing into action theoretically non-structural materials or walls when other members deform undoubtedly accounts for considerable increase in strength beyond calculated failure. Interior partitions, floors, ceilings, and finish materials contribute resistance to loadings ordinarily not imposed on them.

#### 1-4 Nuclear Radiation

The area covered by radioactive fallout represents the largest area covered by an effect of a nuclear detonation. Hazardous levels of fallout can be expected in the downwind direction at distances up to several hundred miles - considerably beyond the range of thermal and blast effects. Up wind, or in the case of an air burst, the hazards of residual radiation may be less critical than those of thermal radiation and blast.

The comments on radiation protection here are limited to residual gamma radiation since prompt-gamma radiation from the explosion is present only in those areas where all nuclear effects are severe and protection is beyond the economic limit of typical single family housing. Neutrons and alpha and beta particles are not dealt with, as their attenuation is not necessarily demanding on the architectural solution other than that of excluding the fallout from the protected area.

To be effective, fallout protection requires skillful planning and cannot usually be accomplished in a building the size of a residence without the introduction of additional massive walls and overhead barriers. Complete fallout protection, or the construction of a house in which all areas are protective, would involve either exorbitant expenditures or a radical change in living habits.

None of the types of radiation emitted has notable effect on the physical characteristics of buildings material. Radioactivity does not alter the structural properties or the appearance of the material exposed, and the materials that attenuate gamma rays do not become radioactive.

All types of nuclear radiation resulting from a nuclear detonation are harmful to human beings, though they cannot be sensed except in very high intensities.

The best method of providing protection from nuclear radiation is through the use of protective structures. Incorporating protective areas within the house, by nature of the construction involved, will also provide a well protected area against the natural phenomena.

Protection may be accomplished by placing a shield between the source and those to be sheltered, or by reducing the intensity of the contributing source. Shielding may be accomplished either by use of geometry or a barrier.

Estimates of the attenuation of residual radiation in typical residential structures have been made, based partly on calculations and partly on measurements with simulated fallout. Some of the results obtained for various locations are given in Table 1-1 for one- and two-story, brick veneer and wood frame houses. The "protection factor" is the ratio of the dose which would be received outdoors, without any protection, to that received at the indicated location in the structure. The values given are fairly representative but should not be regarded as exact. Deviations are to be expected because of differences in construction detail and environment.

Geometry shielding offers protection due to distance from the source of the gamma rays. The gamma ray exposure dose decreases with distance from the source. The relationship is dependent upon two factors similar to those which apply to thermal radiation. First, there is a general decrease due to the spread of radiation over larger areas as it travels. The dose is inversely proportional to the square of the distance from the source. Attenuation is also gained due to absorption

First Floor area (sq ft)	Type of structure							
	One-story brick veneer		One-story frame		Two-story brick veneer		Two-story frame	
	Location							
	Center of grd. fl.	Center of bsmt.	Center of grd. fl.	Center of bsmt.	Center of grd. fl.	Center of bsmt.	Center of grd. fl.	Center of bsmt.
1,000	3.4	22	2.3	20	4.4	54	2.3	44
1,200	3.1	18	2.2	17	4.4	41	2.4	37
1,500	3.1	16	2.3	15	4.4	37	2.4	34
2,000	3.0	14	2.2	13	4.1	34	2.4	29

Table 1-1 Protection Factors at Various Locations in Typical Residential Structures



and scattering of the gamma ray by the intervening atmosphere. To take advantage of geometry shielding in planning, the designer should select a shelter location with maximum distance from sources of contamination. As the ground surface surrounding a structure contributes the majority of the radiation, the central areas of the residence are superior locations. The roof holding fallout contributes heavily to the radiation dose, and to gain maximum distance from this source, the lowest story of the residence should be considered for the shelter location.

Barrier shielding applies the principle that gamma rays are absorbed or attenuated to some extent in the course of their passage through any material. As a rough rule, it may be said that the decrease in the radiation intensity is dependent upon the mass of the material between the source of the rays and the point of observation. It requires a greater thickness of a substance of low density, such as wood, than one of a high density, such as concrete, to attenuate the radiation by a specified amount. If sufficient thickness of material is interposed between the radiation source and an individual, the exposure dose can be reduced to a safe level. The chief materials likely to be available for shielding against nuclear radiation are steel, concrete, masonry, earth, and wood. One inch of steel is equivalent in mass thickness to 4 inches of concrete, to 5 inches of earth, or 16 inches of wood.

To take advantage of barrier shielding, the designer should select materials which are economically feasible and are commonly used in residential construction to provide maximum barrier or mass shielding of a protected area. For instance, he should use the massive materials required for load bearing walls to form barrier walls for the protected area. Since mass materials are generally expensive, the designer should keep the shielded area to a minimum and consider utilizing shelter space for other family functions.

Without altering protection factors, the amount of radiation received may be substantially reduced by partial removal of the fallout material. Natural removal of the fallout material by wind or rain can be encouraged by utilizing details and planning devices which will make decontamination of the area easier, but they should not be expected to be completely effective. Finishes should be as smooth as possible on vertical as well as horizontal surfaces. Decontamination by hosing or sprinkling would require large quantities of water that may be in critical supply and eventually requires a system to remove the collected particles from the immediate area. Vacuuming will generally be a more effective means of decontamination. It is equally important to avoid designs that can trap fallout in critical areas.

## CHAPTER II

### PLANNING PROTECTIVE MEASURES

#### 2-1 Site Planning Considerations

When an architect and his client are selecting a site, a study of natural protection features and landscaping could influence their choice.

Certain aspects of protection from terrain features take advantage of an assumed direction to ground zero. In many cases, especially in suburban areas, the most probable direction can be predicted: toward known defense installations, industrial areas, or the center of a large city. Even when a direction to ground zero cannot be assumed, many landscaping features can be used to reduce the vulnerability of a residence to nuclear effects.

The terrain of the site and of the surrounding area has an influence on the magnitude of the thermal and blast energies received on a house. Grading conditions immediately around the house could have an influence on the amount of radiation received. Since any material which casts a shadow will offer a thermal shield, a house could be situated so that prominent land features shade the residence from the heat wave of a low angle or ground burst. Siting a house on the far side of a hill will also reduce the magnitude of the blast forces received since overpressure values increase when the pressure front ascends an incline and decrease as the front descends. In addition, protection is gained from being on the leeward side of the dynamic winds.

Fallout quantities will not be considerably affected by the terrain surface features, since the period of greatest fallout will occur after the turbulence created by the explosion has subsided. However, grading near the house may be utilized as a barrier shield against fallout and can assist somewhat in the decontamination of the immediate area. Since bodies of water provide self-decontaminating surfaces, projects could take advantage of the smaller area contributing radiation when located near a lake or river.

Some attention should be given to other landscaping elements. Trees on the site may provide a thermal shield but the house should be carefully situated with respect to them as the trees may be susceptible to sustained burning. In addition, the relatively small size of even the largest tree trunk enables it to withstand the overpressures, but the



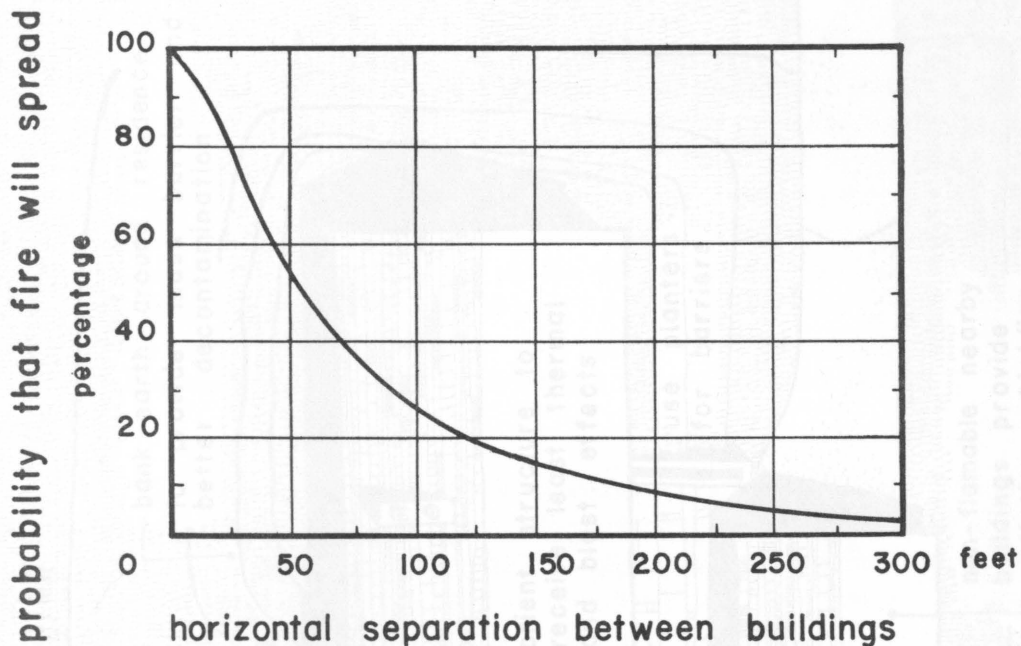
following high winds will undoubtedly cause severe damage. Tornado damage observation shows that where the ground water level is not deep, tree roots pull free, causing considerable damage by breaking portions of street surfaces, curbs and sidewalks. Where ground water level is deep, or where the species have deep tap roots, trees break off five to ten feet above the ground.

Landscaping should be laid out for convenient maintenance. Accumulation of leaves or debris against wooden structures represent a real fire hazard, since the ignition points of grass, dry leaves and pine needles are well below that of painted wood siding.

The other architectural elements in the site development should be planned to take advantage of the benefits they may provide. Paved terraces and drives immediately adjacent to the structure provide an area more easily decontaminated, if their surface is smooth. Solid fences or screens can protect glass areas from thermal radiation. If massive, they will also provide shielding from residual radiation. Pools serve as reservoirs for fire-fighting water, and, since the fallout settles to the bottom, the self-decontaminated surface contributes less harmful radiation.

The advantages and disadvantages of the neighboring structures should be considered. Masonry buildings close by can be regarded as a thermal shield or can provide a barrier shield from fallout. However, if they are flammable, nearby buildings could present a fire hazard. Skillful neighborhood planning could be an effective means of reducing area fires. From Figure 2-1 it can be seen that the distance between buildings should be at least 50 feet if the probability of fire spread is to be limited to 50%, and in order to eliminate the spread of fire almost completely the distance between buildings should be over 300 feet.

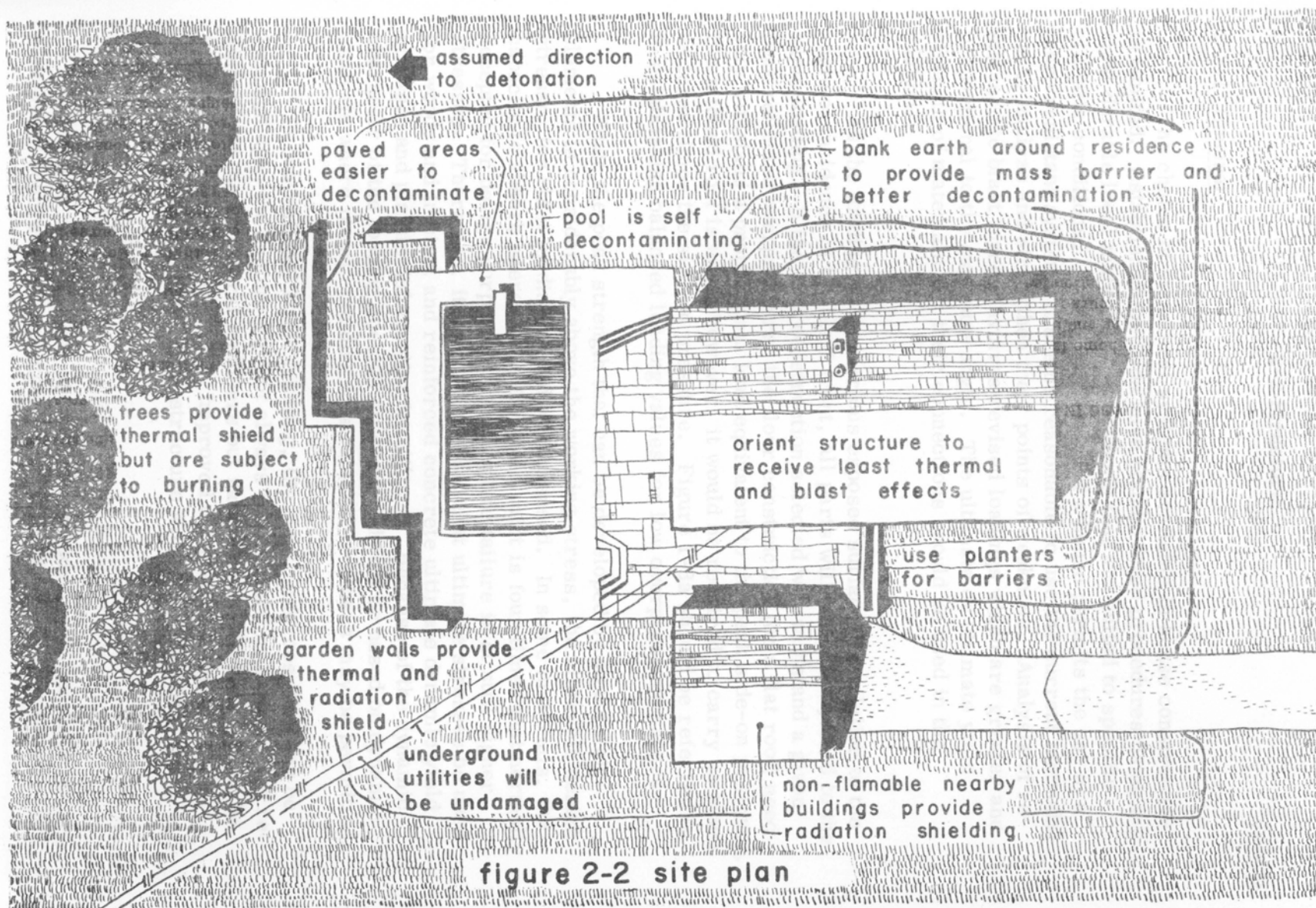
In order to eliminate danger from falling utility poles and to insure continued service, underground utilities are preferable. Damage to underground services beyond the ground shock area is not probable. Damage to water supply is critical for fire fighting. Loss of pressure through breakage of pipes in houses and other buildings is more serious than failure of underground pipes and could be partially remedied by use of flexible connections at the building. Valves should be provided to prevent flow of contaminated water into the residence from the community supply. Individual wells are recommended, as they insure water supply for fire protection and drinking.



**figure 2-1 effect of building separation on fire spread**

If the probable direction of the blast can be assumed, it should be considered in the structural orientation of the house. General orientation of the house should be used to resist the blast forces, since the elevation facing ground zero is subjected to the highest pressures. The effect is not very pronounced in conventional structures which are generally of a rectangular plan, but a long, narrow structure will be more resistant to blast against the end than on the side.

Figure 2-2 illustrates some of the points mentioned above as they could be applied to the site plan of a typical residence.



## 2-2 Structure

### 2-2.1 General

The choice of structural systems available in house construction is limited. Established methods have standardized procedures using the most durable local materials and systems that are suited to specific climatic conditions. Unless the budget of a house permits the use of a more resistant system, it seems reasonable to use the current methods, but to analyze and strengthen their points of weakness. Analysis of resistance to blast forces involves revised loadings which are greater and proportional to the exposure angle. The ultimate or ultimate yield strength of materials and their connections should be used in the analysis.

As the loading on the various exposed surfaces is relative to the angle of incidence of the blast front, all parts will not be subjected to the same loading. If the wall construction selected will withstand a given peak reflected overpressure, the floor construction (or a flat roof) need only withstand a proportional load equivalent to the peak side-on pressure. If a pitched roof is used, however, it would be required to carry as much as three times the side-on pressure. Figure 1-3a should be referred to in establishing balanced loading values for low overpressure ranges.

Since the peak strength that can be developed by structural elements is considerably above the working stress, the allowable design stresses for blast loading should be increased. In some materials, the capacity to absorb energy up to the yield point is four times that normally accepted for design purposes, and complete failure is at still higher stresses. Therefore, it is recommended that ultimate stresses be used for wood, and in steel and reinforced concrete ultimate dynamic yield stresses and plastic deformation be utilized. Because of the dynamic character of the loading, design procedure should be based on dynamic analysis where plastic yielding of structural members may be permitted.

In conventional house framing, the limiting forces that may be imposed upon the system will not always be governed by the ultimate resistance of the structural members but rather by the forces that can be transferred through the joints. Improved connection details must be used or the full efficiency of the structure will not be utilized.

### 2-2.2 Concrete and Steel

A small portion of the house building industry is currently using reinforced concrete and structural steel frames. Both systems are well



suited to blast-resistant design because of their ductility and the continuity achieved at the joints.

Although its relatively high cost limits extensive use in residential construction, reinforced concrete, because of its mass, strength, and resilience, combines the advantage of high blast resistance with excellent fallout protection and incombustibility. It is uniquely qualified as a system for more protective buildings. In those areas of the country where concrete cap beams and columns are used to resist hurricane forces, complete rigid frames can easily be evolved.

Special consideration must be given to detailing to assure continuity and strength for the reversal of load. Shear reinforcement is more necessary and should be at right angles to the axis of the member in order to remain effective under reverse bending.

The ultimate dynamic yield stresses recommended for reinforced concrete are shown in Table 2-1.

In typical residential construction, structural steel is usually used where wood framing is not practical. With structural steel, proper anchorage and connections with floor or roof framing members are critical. Possessing high ductility and by joining through welding, steel has excellent application for blast-resistant systems. Using rigid frames fixed at the foundation, structures of high plastic resistance can be designed.

The recommended design stresses for steel are shown on Table 2-1.

### 2-2.3 Load-Bearing Wall Systems

a. General: The most common building methods today in homebuilding are the load-bearing wall systems of masonry or wood construction. As currently detailed, completed structures have less strength than can be developed in the basic elements of the masonry unit or the framing lumber. More efficient utilization of their strength can be achieved without radically changing construction techniques.

b. Structural response of conventionally framed houses: Eventually, all loading imposed on the structure is transferred to the foundations. The path traveled depends on the framing method and

## CONCRETE

Compression	1.25 f'c
Shear	.25 f'c
Bond	.25 f'c

## STEEL

Tension or compression	42000
Shear	25000
Welds, rivets, bolts	Use yield point values in tension or shear

## FRAMING LUMBER

		Douglas Fir*		Western Hemlock	
		Blast	FHA Allowable	Blast	FHA Allowable
Fiber Stress	C	5800	1200 - 1500	5100	1150 - 1450
	K	2900	200 - 850	2500	200 - 750
Tension	C	5800	1100 - 1300	5100	1000 - 1250
	K	2900	0	2500	0
Horiz. Shear	C	850	95 - 120	850	80 - 100
	K	400	0	415	0
Comp. Parallel to Grain	C	4400	1000	4000	900
	K	2100	0	1900	0
Comp. Perpendicular to Grain	C	650	390	510	365
	K	320	0	250	0
*Use same blast values for Southern Yellow Pine					
C = Clear Material			K = Lumber with largest permissible knot		

## PLYWOOD

Tension and Fiber Bending	6600
Compression parallel or perpendicular to grain	4850
Shear	630
Rolling Shear	240

Table 2-1 Ultimate Design Stresses of Common Structural Materials



detailing. The elements interact indeterminately, and isolation of individual elements is the only practical method of structural analysis.

Vertical loading from the reflected and side-on overpressures and uplift from dynamic forces imposed on the roof are transferred into the walls, and the walls in turn transfer the loads to the foundation.

Horizontal loading may be imposed on both the roof and the wall sections of the house. The main forces tending to overturn or collapse the house are the reflected overpressure and the dynamic wind forces on the wall facing the direction of the blast. For a simplified analysis, the load on this wall may be assumed to be distributed equally to the foundation at the sill and to the roof and ceiling construction at the eaves. It is assumed that the horizontal force at the eaves is transferred through the roof and ceiling construction to the side walls, where it is finally transferred to the foundations. Interior partitions could be used to stabilize the roof through their connections at the ceiling.

For the structural wall elements in a house with short periods of vibration and small plastic deformation at failure, the conditions for failure can be expressed as a peak overpressure without consideration for the duration of the blast wave. The failure conditions for elements of this type are given in Table 2-2.

c. Masonry: Solid masonry, because of its mass, offers better radiation attenuation, and, even without reinforcement, it is able to withstand higher pressures than unstrengthened frame construction. A resistance to 3 to 4 psi can be expected of a 12" brick masonry wall in ordinary construction. In order to achieve 7 to 8 psi resistance, it is necessary to restrain the boundaries of the panels between columns or beams or provide flexural resistance with reinforcing steel.

Observation of a two story masonry residence of conventional construction (4" brick - 4" block) exposed to 5.1 psi showed that, although the walls were probably weakened by the external blast forces, the interior partitions and floor framing provided considerable lateral resistance. Collapse of the structure was caused by the pressure build-up within the dwelling. Conventional framing techniques provide no resistance in this direction.

d. Frame Construction: Because it is an established system in residential construction, the continued use of conventional wood framing may be expected in most home construction. Considering the qualities

STRUCTURAL ELEMENT	FAILURE	APPROXIMATE SIDE-ON BLAST OVERPRESSURE
Glass windows, large and small	Shattering usually, occasional frame failure	psi 0.5-1.0
Corrugated asbestos siding	Shattering	1.0-2.0
Corrugated steel or aluminum paneling	Connection failure followed by buckling	1.0-2.0
Brick wall panel, 8 in. or 12 in. (not reinforced).	Shearing and flexure failures	7.0-8.0
Wood siding panels, standard house construction.	Usually failure occurs at the main connections allowing a whole panel to be blown in.	1.0-2.0
Concrete or cinder-block wall panels, 8 in. or 12 in. thick (not reinforced).	Shattering of the wall	2.0-3.0

Table 2-2 Conditions of Failure of Peak Overpressure-Sensitive Elements

required to resist nuclear effects, wood has low mass-thickness and is a poor barrier to radiation. It has considerable structural resilience and will withstand minor blast pressures. The fire hazards associated with wood can be minimized.

Since the chief fire danger results from the indirect effects of the blast and thermal pulse, fire danger exists even though a structure is properly maintained. In order to minimize the possibility of fire, wood that is pressure-treated with a fire-retardant, can be used for all framing materials, as well as for interior trim, paneling, and plywood sheathings. The additional expense can be partially justified by the termite and decay protection gained in the process, as well as the possibility of reduced insurance costs.

Wood has the remarkable property of being able to carry high loads for short periods of time. However, information regarding its behavior under dynamic loading and experience in its use in blast-resistant construction is limited. In designing frame houses for blast-resistance, it is recommended that the loads be treated as static loads but the ultimate strength of the wood should be used for proportioning the members.

Table 2-1 gives recommended design stresses for framing materials under blast conditions, based on the assumptions that 1) blast loadings are of a relatively short duration; 2) strength of framing members will increase as the wood seasons; 3) safety factors have been omitted.

e. Selection of material: Cost analyses point out that for the strength gained compared with the expenditure, it is more economical to use a higher stress grade of lumber rather than increasing member sizes or decreasing member spacing. A stress grade of 1450f to 1500f is suggested as the minimum to be used for framing lumber. If stress-graded lumber is not available in smaller sizes, the best material should be selected for the exterior or load-bearing walls. This material should be as free of strength-reducing characteristics as possible. Small knots should be away from the edges and the grain should be as nearly parallel to the edges as possible. Although wood will increase in strength as it dries, the shrinkage around nail holes will decrease the effective strength of connections. Material with a high moisture content should be avoided.

f. Connections: In wood framing, connections are critical points, and it is difficult to design an efficient connection. In conventional

framing, member sizes have already been increased to accommodate the required connectors.

The most common connector for wood is the wire nail. This connector loses much of its initial holding power when green lumber is used and dries during service conditions. Tests based on a two-thirds penetration (rarely achieved in the field) show that a  $2\frac{1}{2}$ -inch common nail has a withdrawal resistance of 264 pounds and a lateral load carrying capacity of 500 pounds. After the wood has dried, these values drop to 77 pounds and 415 pounds. Clinching the nail increases withdrawal and lateral load-carrying capacity by 50%. Toenailing reduces the withdrawal resistance value of the nail by one third and lateral loading by one sixth. Since the quality of toenailing is so difficult to control, it is best to avoid the use of this method of fastening wherever possible.

Special nails with deformed shanks have higher initial holding power and there is less loss as the lumber dries. A  $2\frac{1}{2}$ " helically threaded nail loses withdrawal resistance from 331 pounds to 223 pounds and lateral load-carrying capacity from 751 pounds to 731 pounds. A  $2\frac{1}{2}$ " annularly grooved nail loses withdrawal resistance from 644 pounds to 524 pounds and lateral load-carrying capacity from 620 pounds to 580 pounds. Special nails are available for any use and can provide more efficient structural connections as well as fasten paneling, sheathing and trim more securely.

The most difficult connection is the tension joint. For this connection, metal framing anchors should be considered, as they eliminate much of the uncertainty of workmanship of toenailing and end-nailing and they load the nail in the most efficient manner. The anchor is formed from 20-gage metal and is fastened by special nails through pre-punched holes.

Other standard types of connectors, such as joist hangers, could be easily adapted to other applications than those for which they are primarily intended. Again, their ultimate value should be utilized. This value is usually about four times the recommended design values for short-term loading. Straps or plates can be made inexpensively and simple devices can be designed for particular situations.

g. Fixity and continuity: Studies of rigid frames show that using pinned connections at column bases and rigid connections between columns and beams is a convenient method of achieving an efficient system. One of the best methods of achieving fixed joints is through plywood gussets or splice plates, attached with glue. Continuity can be achieved by using continuous members to avoid splicing, such as in floor joists, and by

balloon framing the gable ends and two-story elements. Where continuity is not practical, such as framing around masonry chimneys or stair wells, special attention should be given to the concentration of stresses at these points.

h. Stressed skin construction: Plywood has high ultimate strength and, when glued to high stress-grade framing lumber to form a stressed-skin panel, the strength of the section is increased considerably at very small additional cost. Plywood subfloors and wall and roof sheathing can be combined with framing members to form composite sections.

Field gluing is difficult to control, and certain precautions must be taken. Casein glues are easiest to use and may be used at any temperature above freezing. Waterproof glues are more costly and require high temperatures for curing. For adequate bond, moisture content of the members to be glued should be below 16%.

Flexural tests of plywood show a fiber stress of 6,900 to 8,500 psi at the proportional limit, which compares favorably to the values obtained for solid Douglas fir. Certain characteristics, such as knots, knotholes, and pitch pockets, reduce the cross-sectional area. Accordingly, the basic stress for the clear material must be reduced for each of the several grades of plywood. For C-D sheathing grade, it is conservative to allow a 25% reduction from the clear-grade unit stresses. Lower reductions are permissible for the better grades. If the factor of safety is removed, and it is assumed the moisture content remains under 16% and that the duration of the loading is under five seconds, the stress values shown on Table 2-1 may be used.

## 2-3 Foundations and Basements

### 2-3.1 Planning Considerations

If the residence is in an area where basement construction is feasible, the natural advantage of below grade construction should be utilized to provide less expensive and efficient shelter space. Maximum fallout protection will be provided if the entire shelter area is below finished grade. If part of the basement is above grade, there is a greater contribution of radiation through walls and windows. Solid masonry cross walls should be used to help resist lateral loads as well as to define the shelter areas.

Openings in the basement walls should be limited since glass



presents no effective barrier to the gamma radiation. Also, it will not attenuate thermal radiation, and will shatter at very low overpressures. Where windows are necessary, wire glass, a protective inside screen of hardware cloth, or a baffle system should be used to limit the danger from flying glass.

As the least vulnerable area, the basement could provide quite usable temporary living space. A possible design could anticipate the loss of the superstructure, and place special emphasis on planning a habitable basement area. Structural details would allow failure at the sill connection, minimizing the stresses induced in the first floor framing system, which would serve as the shelter ceiling and roof. The floor system could be easily designed to withstand higher overpressures than the complete house structure and, in addition, take the load of the collapsed structure. A poured concrete floor system would be excellent for this purpose. Obvious design considerations would include the provision of an auxiliary exit, inclusion of toilet facilities, and the zoning of the heating system.

### 2-3.2 Structural Consideration

Loadings on the foundations or basement walls result chiefly from forces transferred to them from the superstructure. In tests conducted on a residence at the Nevada test site, where the air shock wave was estimated at 5 psi, the basement wall below grade suffered minor damage, indicating a relatively minor ground shock wave.

Loads transferred from the superstructure, which will vary with the size, shape and orientation of the house, should be calculated on the basis of the load which can be carried or transmitted by the weakest member or connection in the superstructure. As a result of loading by overpressure, reflected overpressure, and dynamic wind forces, both vertical and lateral loading will be imposed on the foundation. Vertical compressive forces transmitted from the roof, as well as the dead load of the house present no problem since they resolve into vertical axial loads tending to stabilize the foundation walls. Tension forces, resulting from wind uplift or the vertical component of the overturning force on the structure, require stronger connections at the sill than those currently used.

The action of the house should be studied under loading received from each of its orientations. The forces due to the negative phase of the blast front need not be calculated if the positive pressures have been

studied from all directions. The forces acting on the foundations result from three possible movements of the house illustrated in Figure 2-3: overturning, translation, and rotation. In studying the action of these forces, it should be assumed that the soil pressure and force of gravity provide the resistance to these forces. In the case of vertical compressive forces transferred into the soil, soil bearing capacities may be doubled since the loadings are of short duration. Lateral forces tending to cause vertical uplift reactions are resisted by the dead load of the structure above, the available live load, and the weight of the footings and foundation walls.

### 2-3.3 Materials

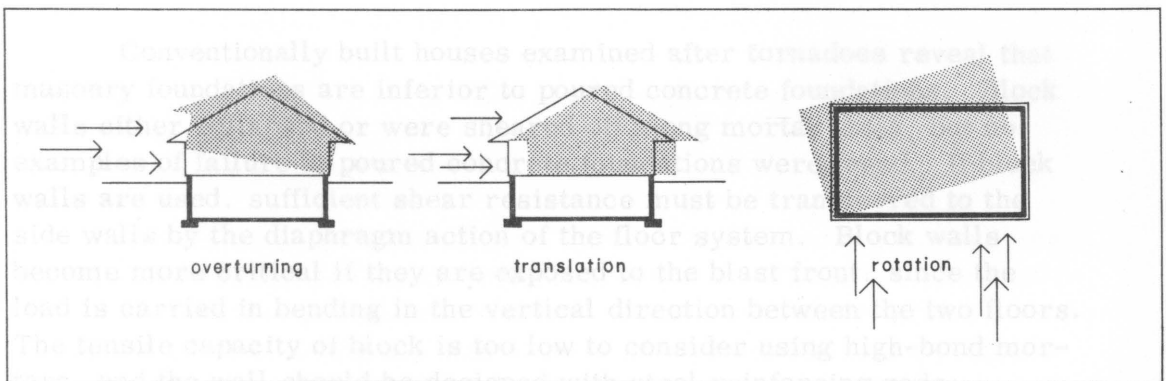


figure 2 - 3 movement of house on foundation

The overturning tendency, which results from the reflected overpressure on the wall facing the blast, is in part resisted by the mass of the superstructure. It is critical in narrow two-story elements where the length of the moment arm of the overturning force approaches the length of the moment arm of the resisting dead load. The unbalanced moment, resisted by the mass of the footings under the blast face of the structure, requires transfer of tension forces through the sill. Special attention must be given to basementless houses in areas where footings near the ground surface provide negligible resistance.

Translation, also resulting from unequal pressures, is the tendency of the entire structure to slide on the foundation. Low structures are more subject to translation than two-story ones. Resistance is gained from the friction due to the weight on the foundation plus the

resistance in shear of the anchor bolts on the entire perimeter. Distribution of the load to the entire perimeter relies on a rigid floor structure. The resultant forces will be resisted by the passive earth resistance on the leeward face and by shear in the end walls. Failure to transfer the force through the floor system will subject the foundation wall facing the blast to bending stresses.

Rotational movement will be developed in residences with unsymmetrical facades where the resultant action of the overpressure force does not coincide with the centroid of the resisting elements. The effects on the foundation and the sill are similar to the effects of translation.

### 2-3.3 Materials

Conventionally built houses examined after tornadoes reveal that masonry foundations are inferior to poured concrete foundations. Block walls either collapsed or were sheared off along mortar lines, but no examples of failure in poured concrete foundations were found. If block walls are used, sufficient shear resistance must be transferred to the side walls by the diaphragm action of the floor system. Block walls become more critical if they are exposed to the blast front, since the load is carried in bending in the vertical direction between the two floors. The tensile capacity of block is too low to consider using high-bond mortars, and the wall should be designed with steel reinforcing rods.

Cross walls in the basement of a two-story house tested in Nevada were effective in resisting the movement of the first floor construction. However, it was concluded that where the first-floor framing is rigid and is properly anchored to basement walls, such shear walls may be unnecessary.

### 2-3.4 Construction Details

Since the transfer of all the forces must be made through the critical sill detail, the numerous possible methods of failure at this point should be studied. The anchor bolt must be long enough to develop sufficient bond to resist uplift forces. The cross section of the anchor bolt must be large enough to resist the tensile and shearing forces. The washer at the top of the anchor bolt must be large enough to prevent crushing of the wood sill. The wood must be thick enough or the bolt large enough to provide bearing to resist the lateral forces.

The corrective measures taken should be in proportion to those taken for the entire residence. One-half-inch bolts spaced eight feet on center, as required in conventional construction will be adequate only under the lightest loading. To obtain strength compatible with the most resistive construction proposed in this guide, anchor bolts 3/4" in diameter spaced four feet on center must be used. The sill condition shown in Figure 2-4a illustrates a conventional platform sill detail. All lateral forces received by the wall must be transferred into the sill by the toenailing in the header. The condition can be greatly improved by extending the plywood wall sheathing beyond the sill as shown in Figure 2-4b. The modified balloon frame shown in Figure 2-4c eliminates transferring forces through a toenailed connection. A metal anchor is recommended to transfer outward forces resulting from overpressures or reflected overpressures which build up within the structure.

## 2-4 Walls and Partitions

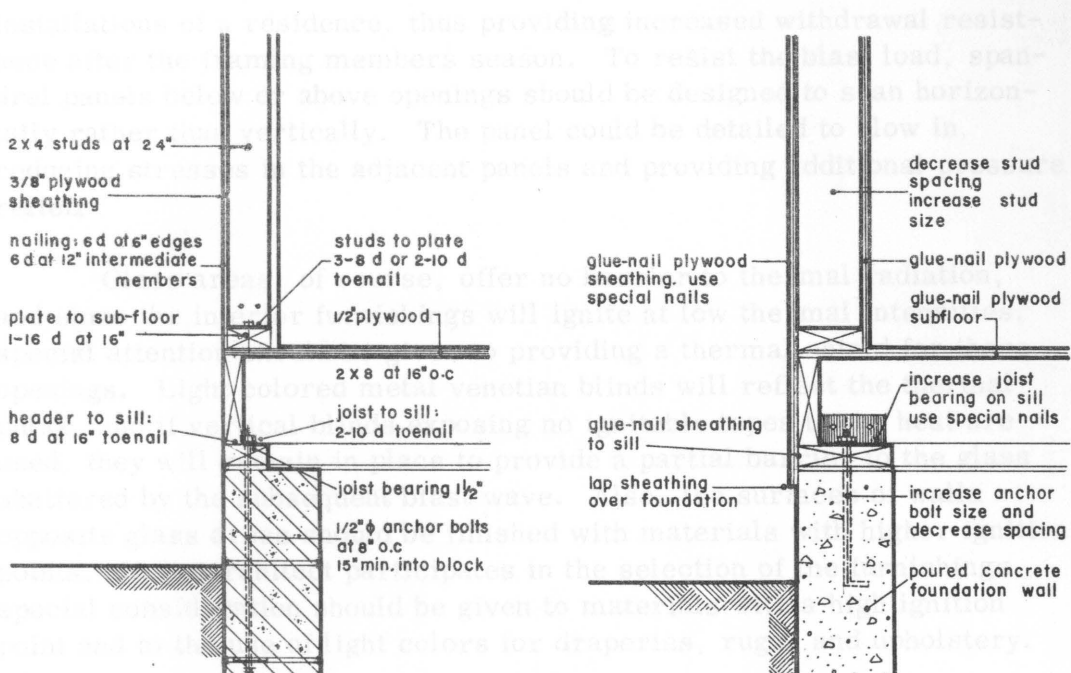
### 2-4.1 Design Considerations

All vertical surfaces facing a nuclear detonation will be subjected to reflected overpressures and thermal radiation. Therefore it is desirable that the house be oriented in such a manner that there will be a minimum surface facing the detonation. This presumes that a probable target area can be predicted. Interior partitions, exposed to lesser forces, should be arranged to contribute reinforcement to the walls subjected to high loading, but partitions should be arranged so they will not form high pressure traps.

In addition to providing pressure relief, openings in exterior walls reduce the exposed area, thus reducing the total loading applied on the surface. However, openings in the walls parallel to the blast direction reduce the effective shear strength of the wall and should be minimized and located as far as possible from the wall intersections without interfering with the plan.

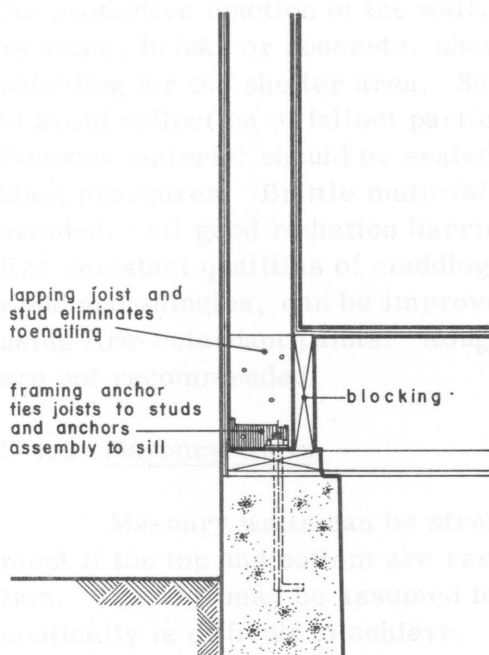
Glass shatters at low overpressures, and the danger from flying glass extends to areas where little other damage can be expected. The minimum blast protection that should be incorporated within a residence would be to provide at least one glass free area.

Frames around openings are loosened and damaged at very low overpressures. For a very small cost increase deformed shank nails can be substituted for plain shank nails on all window and door frame



conventional platform framing (a)

modified platform framing (b)



modified balloon framing (c)

scale: 3/4"=1'-0"

figure 2-4 sill details



installations of a residence, thus providing increased withdrawal resistance after the framing members season. To resist the blast load, spandrel panels below or above openings should be designed to span horizontally rather than vertically. The panel could be detailed to blow in, reducing stresses in the adjacent panels and providing additional pressure relief.

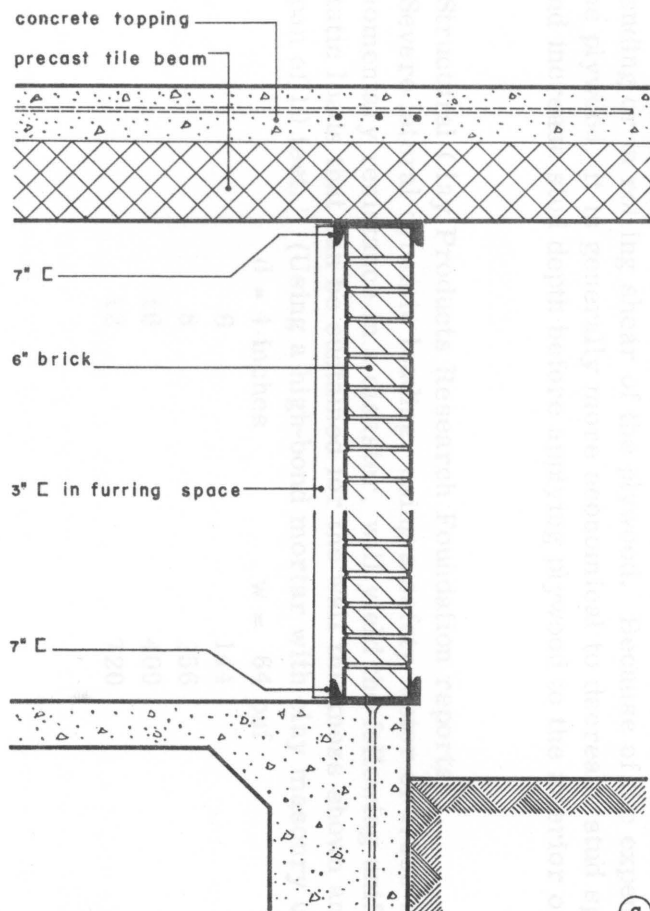
Glass areas, of course, offer no barrier to thermal radiation, and since the interior furnishings will ignite at low thermal intensities, special attention should be given to providing a thermal shield for these openings. Light colored metal venetian blinds will reflect the thermal pulse, and if vertical blinds exposing no ignitable tapes to the heat are used, they will remain in place to provide a partial barrier to the glass shattered by the subsequent blast wave. Also, the surfaces of walls opposite glass areas should be finished with materials with higher ignition points. If the architect participates in the selection of the furnishings, special consideration should be given to materials with a high ignition point and to the use of light colors for draperies, rugs, and upholstery.

#### 2-4.2 Material Selection

Material selection for walls and wall surfaces should be based on radiation attenuation or blast and fire resistant qualities, depending on the protective function of the wall. Walls of high mass thickness, such as stone, brick, or concrete, should be used where they will provide shielding for the shelter area. Surfaces should be as smooth as possible to avoid collection of fallout particles and to facilitate decontamination. Poursous material should be sealed. Resilient materials better withstand blast pressures. Brittle materials such as cement asbestos should be avoided. All good radiation barriers are relatively incombustible. The fire resistant qualities of cladding materials for frame walls, such as wood and shingles, can be improved by painting with light colors or by using fire-retardant paints. Rough sawn and natural weathered sidings are not recommended.

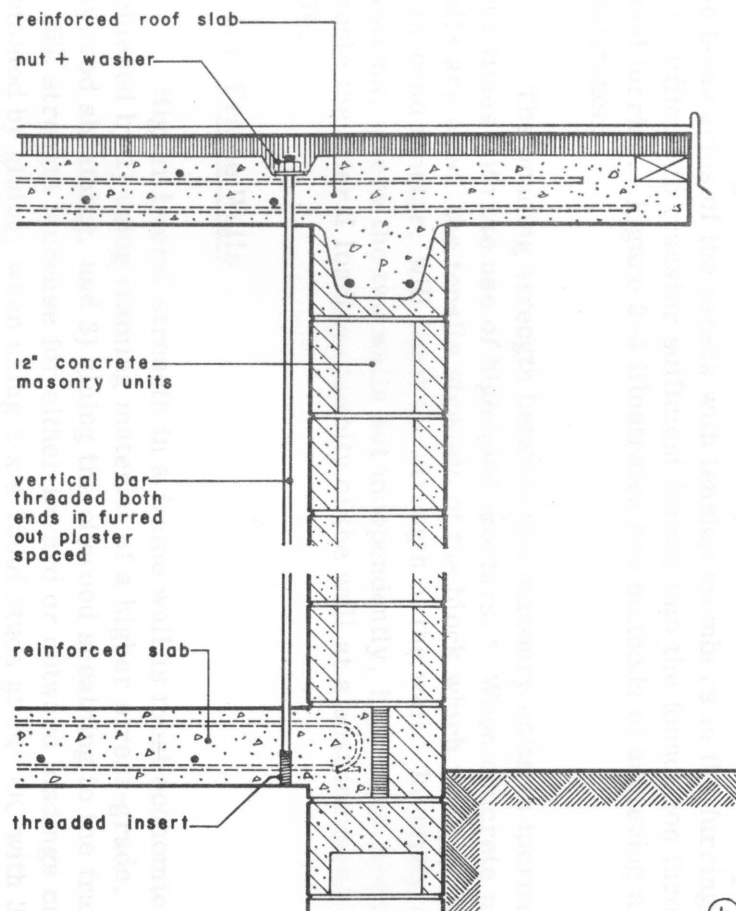
#### 2-4.3 Masonry Walls

Masonry walls can be strengthened by providing tensile reinforcement if the top and bottom are restrained by the ceiling and floor construction. The wall may be assumed to be a simple vertical span since continuity is difficult to achieve. With additional reinforcement at the base, some moment can be transferred into the foundation.



scale:  $\frac{3}{4}'' = 1' - 0''$

arched clay masonry wall section  
as proposed by structural clay products research foundation



scale:  $\frac{3}{4}'' = 1' - 0''$

reinforced concrete masonry wall section  
as proposed by portland cement association

figure 2-5 strengthened masonry walls

Arching of reinforced masonry walls can be achieved by tying the boundaries of the panels with tension members in the furring space. It is difficult to transfer sufficient forces into the foundation through wood furring. Figure 2-5 illustrates two methods of achieving arching resistance.

The bonding strength between the masonry units is increased four times with the use of high-bond mortars. \* When concrete masonry units are used, the tensile strength of the block, which is below that of high-bond mortar, will limit the strength of the wall. In cavity wall systems, where the two walls act independently, high-bond mortars will double the lateral loading capacity of the wall at a cost increase of about 15%.

#### 2-4.4 Frame Walls

Higher lateral strength in a frame wall is most economically achieved by 1) using framing material of a higher stress-grade, 2) using plywood sheathing, and 3) gluing the plywood sheathing to the framing. A 25% strength increase for either inward or outward loadings can be obtained by gluing, when using 2 x 4 1500f studs at 24" OC with 3/8" plywood sheathing.

The tables in section 7 of this chapter list various wall sections with strength and cost increases based on a 26' x 52' house. The mode of failure of these wall sections varies; either in compression on reverse bending or in rolling shear of the plywood. Because of the expense of the plywood, it is generally more economical to decrease stud spacing and increase stud depth before applying plywood to the interior of the wall.

#### 2-5.1 Design Considerations

\*Structural Clay Products Research Foundation reports:

"Severe lateral dynamic loading, using a safety factor of 1.333 for momentary resistance in a disaster, will yield the following uniform static loads that can be sustained for the wall thickness shown and a span of 10 feet." (Using a high-bond mortar with clay masonry units).

d = 4 inches	w = 64 psf
6	144
8	256
10	400
12	720

Plywood, in addition to providing greater bending resistance, increases the racking resistance of the wall. By using full height sheets, the plywood can be used to transfer the horizontal loading from the wall into the sill at the foundation or from the wall into the roof construction at the eave. In most cases the plywood is sufficiently strong to transfer the load that can be imposed upon the wall. Figures 2-4, 2-7 and 2-10 illustrate methods of achieving this transfer at sill and eave conditions.

The detail of framing upper floor levels into the exterior walls is a critical point. The present practice of using platform framing illustrated in Figure 2-6a breaks the continuity of the wall studs, and the use of eight-foot sheets of plywood for sheathing provides no vertical tie at the joint. Ballon framing, as shown in Figures 2-6g and 2-6h, with glued and nailed plywood, will provide both a vertical tie and continuity at this joint.

In masonry construction, the intermediate floor construction is important in resisting the lateral loads on the wall. However, unless joist anchors are installed, as shown in Figures 2-6e and 2-6f, the wall receives no benefit from the floor construction when subjected to the internal exploding forces.

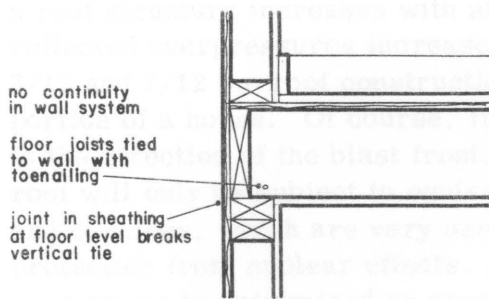
## 2-5 Roofs, Ceilings and Floors

Horizontal planes serve as overhead barriers for fallout protection and are used structurally to transfer lateral loading to shear walls, in addition to carrying vertical loadings.

### 2-5.1 Design Considerations

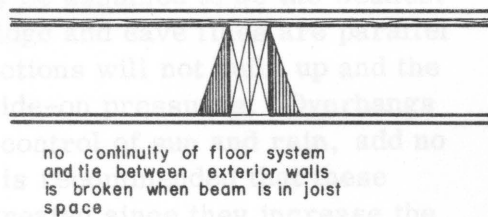
Because a major element in the architectural design of a residence is the form of the roof, the inherent resistance to nuclear effects of various shapes should be considered. A flat roof exposes the least surface to the thermal wave and it provides a rigid plane to transfer the reflected overpressures received on the front wall to the other walls. However, it is subject to more uplift from the dynamic forces. Because flat roofs do not drain rapidly and because the surfacing material is generally rough, decontamination is difficult.

A sloped roof, though exposing more surface to a thermal front, is less subject to uplift forces, decontaminates more easily, and the additional height adds some geometry shielding. Though the strength of

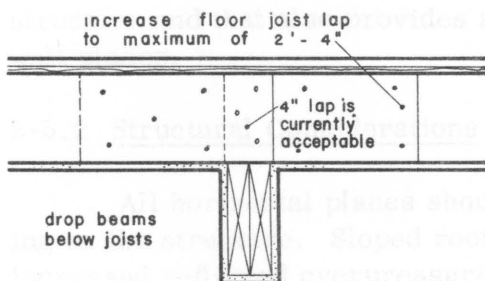


conventional platform framing

(a)

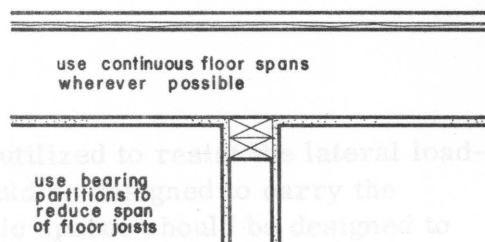


(b)



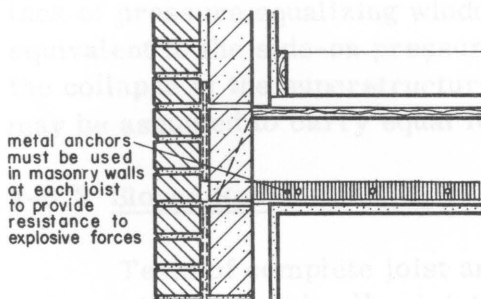
joist splice

(c)



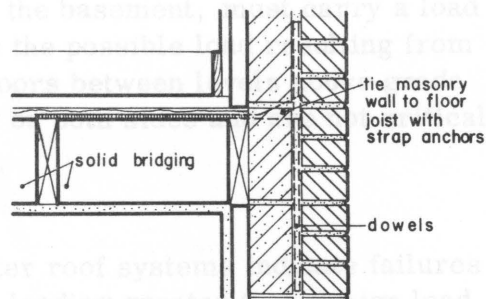
bearing partition

(d)



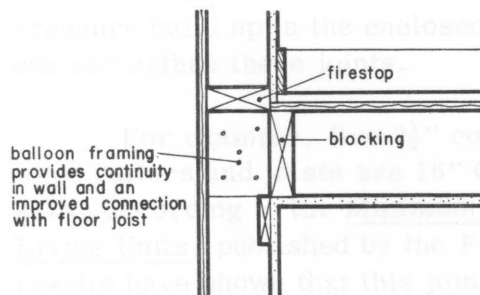
8" masonry side wall

(e)



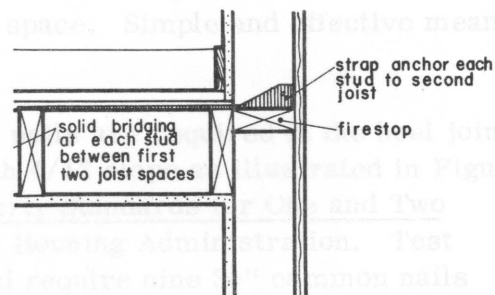
8" masonry end wall

(f)



modified balloon framing side wall

(g)



modified balloon framing end wall

(h)

scale:  $\frac{3}{4}'' = 1'-0''$

figure 2 - 6 second floor framing details



a roof structure increases with slope, the proportion of loading from reflected overpressures increases more rapidly. At slopes between 3/12 and 7/12 the roof construction may be assumed to be the weakest portion of a house. Of course, if the ridge and eave lines are parallel to the direction of the blast front, reflections will not build up and the roof will only be subject to equivalent side-on pressures. Overhangs and cornices, which are very useful in control of sun and rain, add no protection from nuclear effects, and it is recommended that these projections be minimized or specially treated since they increase the roof area affected by blast pressures. Figure 2-7c illustrates a suggested eave detail that will not transfer the overhang loading into the structure and that also provides an excellent tie between the roof and wall planes.

### 2-5.2 Structural Considerations

All horizontal planes should be utilized to resist the lateral loading on the structure. Sloped roofs should be designed to carry the increased reflected overpressure. Attic spaces should be designed to resist the explosive effect. Flat roofs must be designed to carry a load equivalent to the side-on overpressure. Floors over basements, due to lack of pressure equalizing windows in the basement, must carry a load equivalent to the side-on pressure plus the possible load resulting from the collapse of the superstructure. Floors between levels above grade may be assumed to carry equal loading on both sides and are not critical.

### 2-5.3 Sloped Roofs

Tests of complete joist and rafter roof systems indicate failures occur at the heel and collar joints with loading greater than design load but considerably less than the strength of the framing members. Testing under blast conditions indicates that failure at the peak occurs from a pressure build up in the enclosed attic space. Simple and effective means can strengthen these joints.

For example, five 3½" common nails are required in the heel joint when rafters and joists are 16" OC with 4/12 slope as illustrated in Figure 2-7a, according to the Minimum Property Standards for One and Two Living Units, published by the Federal Housing Administration. Test results have shown that this joint would require nine 3½" common nails to transfer the strength of only 2 x 4 rafters. As the rafters dry and increase in strength, the shrinkage around the nails will decrease their

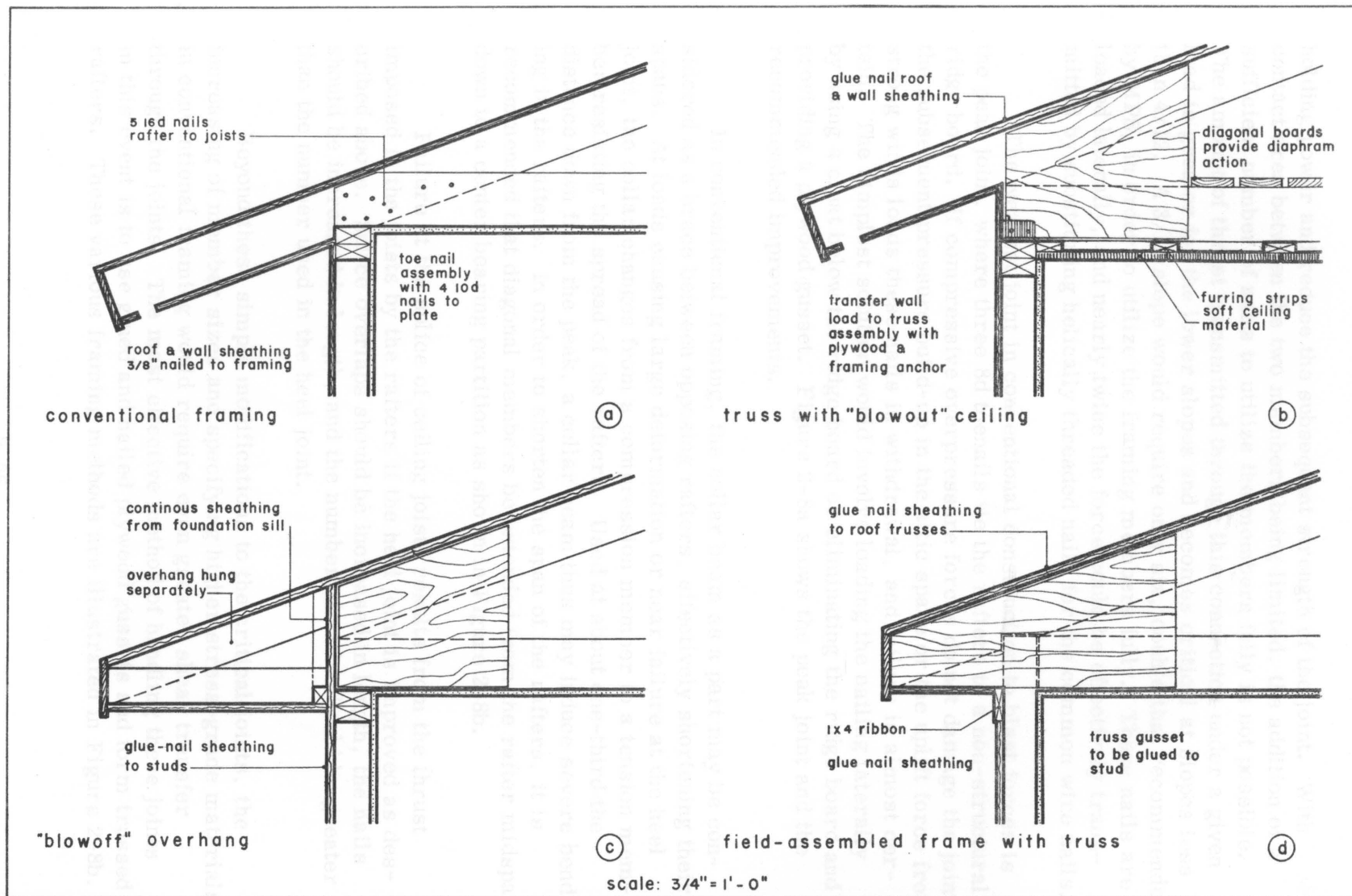


figure 2-7 heel joint details

holding power and reduce the subsequent strength of the joint. With contact area between the two members being limited, the addition of a sufficient number of nails to utilize the members fully is not possible. The amount of thrust transmitted through this connection under a given load is greater for the lower slopes and becomes critical at slopes less than 4/12. A 3/12 slope would require only six, double that recommended by MPS, in order to utilize the framing members fully. These nails are loaded laterally, and nearly twice the force could be effectively transmitted by substituting helically threaded nails for the common wire nails.

The weakest joint in conventional construction to blast forces is the peak joint, where three 8d toenails tie the rafters to a non-structural ridge board. If compressive overpressure forces do not damage the joint, the subsequent pressure build-up in the attic space or the uplift force from strong winds loads these nails in withdrawal, and failure is almost certain. The simplest solution would involve loading the nailing laterally by using a cleat below the ridge board or eliminating the ridge board and providing a plywood gusset. Figure 2-8a shows the peak joint and the recommended improvements.

In conventional framing, the collar beam as a part may be considered as a brace between opposing rafters, effectively shortening their spans. At loads causing large deformation or near failure at the heel joint, the collar changes from a compression member to a tension member resisting the spread of the rafters. Used at about one-third the distance down from the peak, a collar beam thus may induce severe bending in the rafters. In order to shorten the span of the rafters, it is recommended that diagonal members be extended from the rafter midspan down to a center bearing partition as shown in Figure 2-8b.

Failure at the splice of ceiling joists results from the thrust imposed in the joists by the rafters if the heel joint is improved as described above. Splice overlaps should be increased in length, the nails should be increased in length, and the number of nails should be greater than the number used in the heel joint.

Beyond these simple modifications to the critical joints, the increasing of member sizes and specifying higher stress-grade materials in conventional framing would require even greater shear transfer through the joints. The most effective method of handling these joints in this event is to use glued and nailed plywood gussets and form trussed rafters. These various framing methods are illustrated in Figure 2-8b.

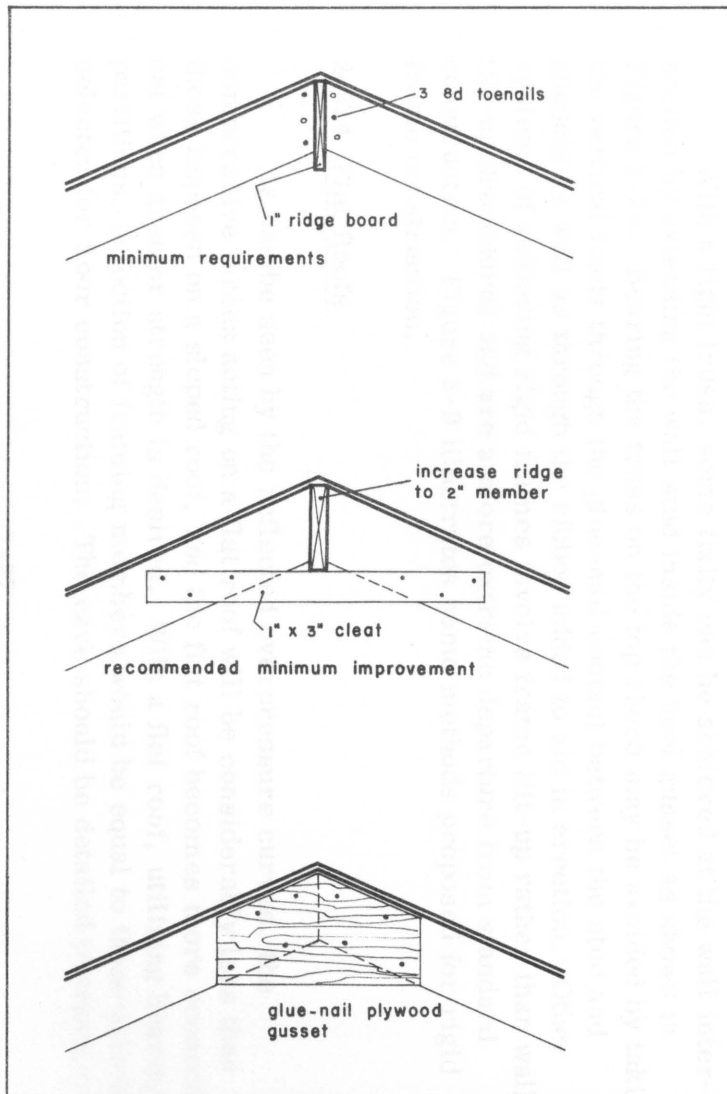


figure 2-8a ridge peak details

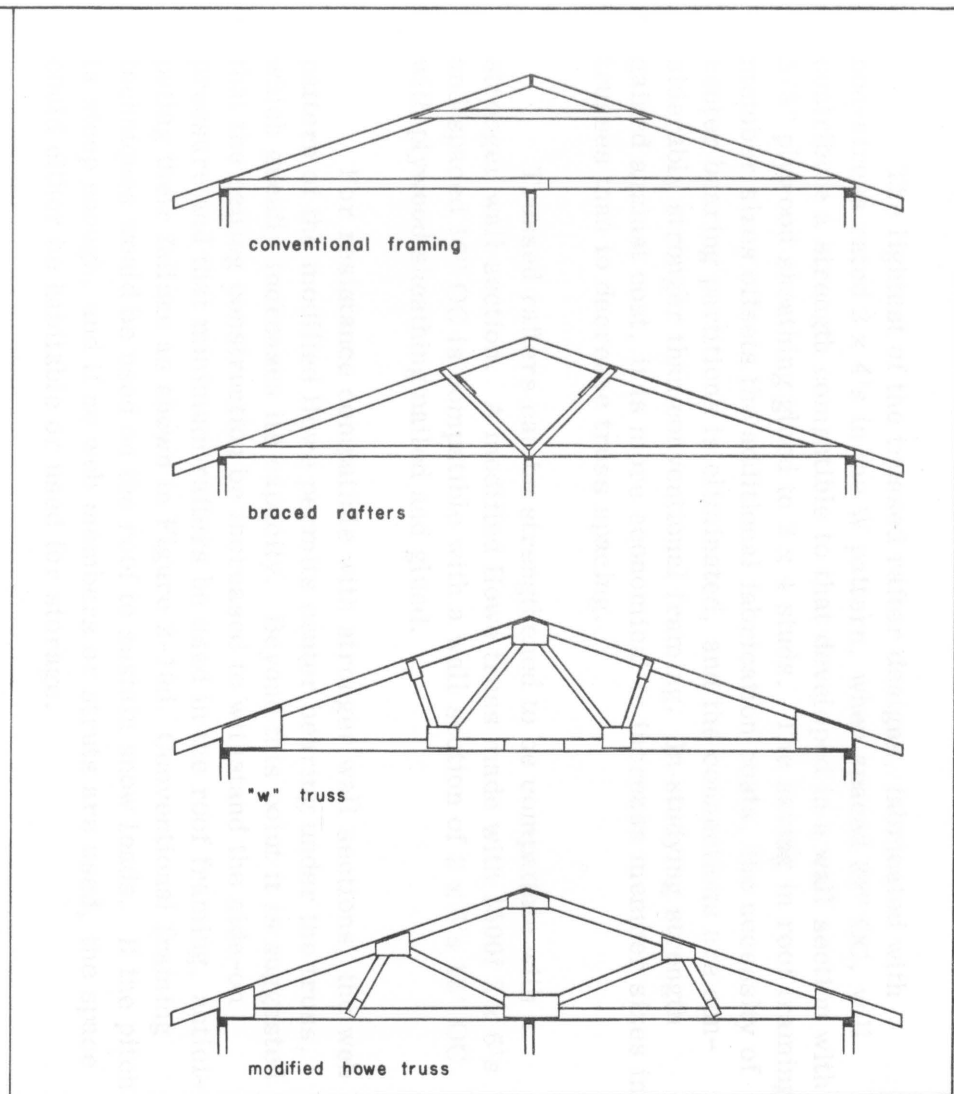


figure 2-8b slope roof framing systems

The lightest of the trussed rafter designs, fabricated with non-stress rated 2 x 4's in the W pattern, when spaced 24" OC, will contribute a strength compatible to that developed in a wall section with 3/8" plywood sheathing glued to 2 x 4 studs. The saving in roof framing member sizes offsets the additional fabrication costs, the necessity of center bearing partitions is eliminated, and the connections are considerably stronger than conventional framing. In studying strength gained against cost, it is more economical to increase member sizes in trusses than to decrease truss spacing.

Trussed rafters can be strengthened to be compatible with a stronger wall section. A modified Howe truss made with 1500f 2 x 6's and spaced 16" OC is compatible with a wall section of 2 x 6's 16" OC with plywood sheathing nailed and glued.

For resistance compatible with stronger wall sections, the web pattern of the modified Howe permits center bearing under the truss, which greatly increases its capacity. Beyond this point it is suggested that the ceiling construction be increased to withstand the side-on pressure and that minimum rafters be used in the roof framing, anticipating their failure as shown in Figure 2-10d. Conventional framing techniques would be used on the roof to sustain snow loads. If the pitch is steep enough, and if no web members or struts are used, the space could either be habitable or used for storage.

With a light truss, some fixity can be achieved at the wall intersection by extending the wall stud inside the heel gusset as shown in Figure 2-7e. Bearing the truss on the top chord may be avoided by taking the vertical loads through the glue-nail contact between the stud and gussets as well as through the ribbon added to aid in erection. Other systems of achieving rigid frames involve frame tilt-up rather than wall tilt-up procedures and are a more extreme departure from standard construction. Figure 2-9 illustrates some methods proposed for rigid frame construction.

#### 2-5.4 Flat Roofs

As can be seen by the reflected overpressure curves, the compressive forces acting on a flat roof will be considerably less than those imposed on a sloped roof, and the flat roof becomes more economical when greater strength is desired. With a flat roof, utilizing bearing partitions, selection of framing members would be equal to those members selected for floor construction. The eave should be detailed to transfer



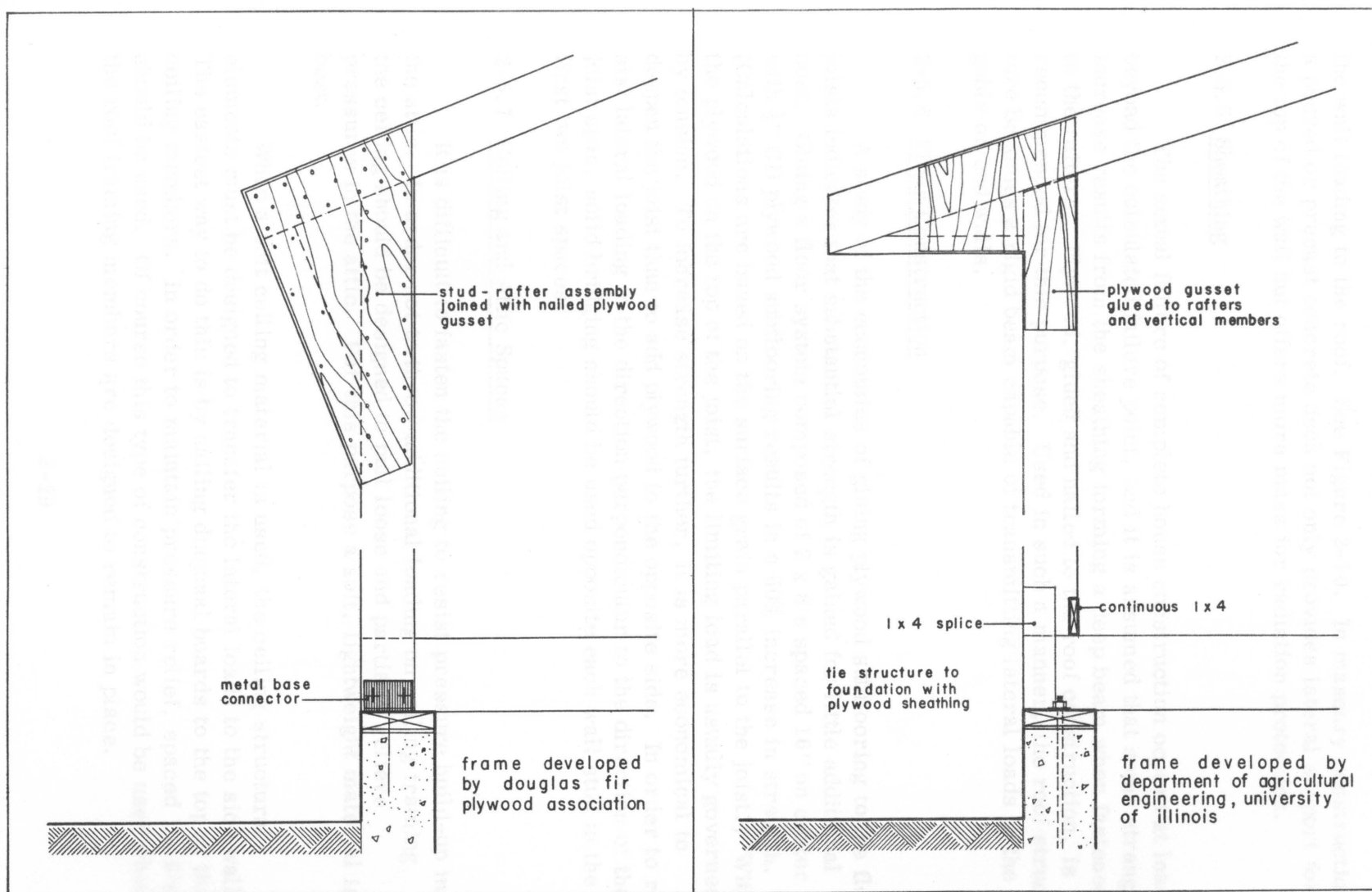


figure 2-9 rigid frames of wood

the wall loading to the roof. See Figure 2-10. In masonry construction, a poured or precast concrete deck not only provides lateral support for the top of the wall but offers more mass for radiation protection.

#### 2-5.5 Sheathing

The actual failure of complete house construction occurs at loading beyond the calculated failure point, and it is assumed that some strength increase results from the sheathing forming a deep beam when fastened to the rafters. Plywood, glued and nailed to the roof construction, is recommended for this purpose. Used in such a manner, the roof structure becomes a rigid beam capable of transmitting lateral loads to the gable or end walls.

#### 2-5.6 Floor Construction

A study of the economies of gluing plywood subflooring to the floor joists indicates that substantial strength is gained for little additional cost. Gluing a floor system composed of 2 x 8's spaced 16" on center with  $\frac{1}{2}$ " CD plywood subflooring results in a 60% increase in strength. (Calculations are based on the surface grain parallel to the joist.) With the plywood on the top of the joist, the limiting load is usually governed by tension. To increase strength further, it is more economical to deepen the joist than to add plywood to the opposite side. In order to resist lateral loading in the direction perpendicular to the direction of the joist span, solid bridging should be used opposite each wall stud in the first two joist spaces.

#### 2-5.7 Ceiling and Attic Spaces

It is difficult to fasten the ceiling to resist pressure build-up in the attic. In order not to throw additional loading on ceiling framing, the ceiling should be designed to pull loose and partially relieve pressures in the attic. For this purpose a soft, lightweight material is best.

When a soft ceiling material is used, the ceiling structural elements must be designed to transfer the lateral loads to the side walls. The easiest way to do this is by nailing diagonal boards to the top of the ceiling members. In order to maintain pressure relief, spaced 1 x 6's should be used. Of course this type of construction would be used where the roof framing members are designed to remain in place.

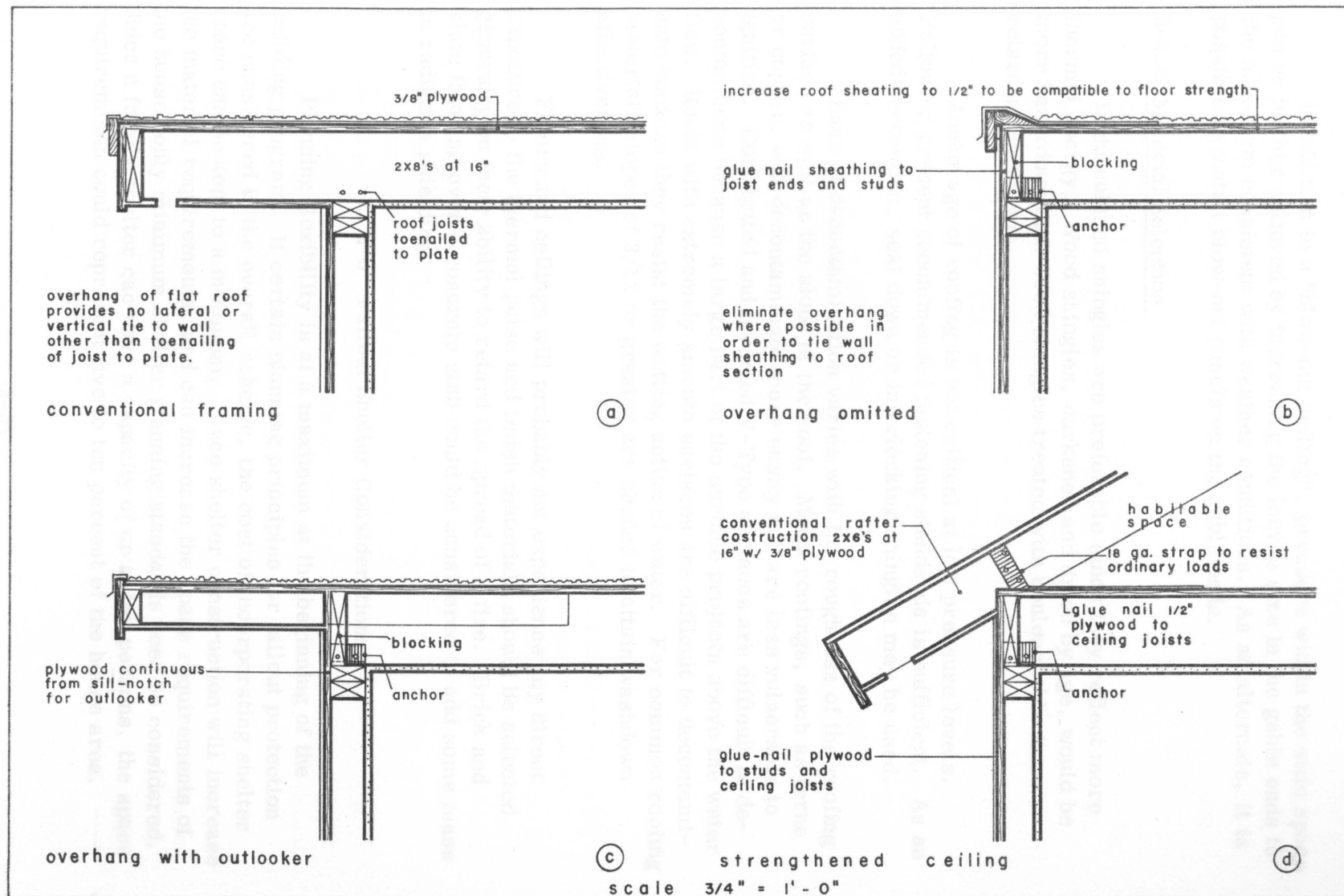


figure 2 - 10 flat roof details

In addition to a "blow-out ceiling", pressure within the attic space can be further relieved by increasing the louvre size in the gable ends to the maximum consistent with weather conditions. As an alternate, it is possible to install blow-out panels on the gable ends.

#### 2-5.8 Material Selection

Light colored shingles are preferable since they reflect more thermal energy. Wood shingles, darkened and dried by age, would be more hazardous than wood shingles treated with nonleachable fire-retardant chemicals.

Anchorage of roofing is not critical at low pressure levels. Following present recommended fastening standards is sufficient. As an added precaution, seal down or interlocking shingles may be used.

Ease of decontamination varies with the roughness of the roofing surface as well as the slope of the roof. Metal roofings, such as terne or copper, will decontaminate more easily and are less vulnerable to ignition. Corrugated and inverted V-Type surfaces are difficult to decontaminate because a large part of the surface projects above the water flow. Roofs with extremely smooth surfaces are difficult to decontaminate because they resist the wetting action of water. For common roofing materials slopes of 3/12 or greater are needed to attain washdown effectiveness.

Floors and ceilings will probably not experience any direct exposure to the thermal pulse and finish materials should be selected generally on their ability to retard the spread of a fire. Brick and slate flooring over a concrete slab could be considered to add some mass in radiation shielding.

#### 2-6 Fallout Shelter Considerations

Planning flexibility is at a maximum at the beginning of the building program. If certain planning principles for fallout protection are considered in the overall scheme, the cost of incorporating shelter space can be kept to a minimum. Since shelter construction will increase the material requirements, and can increase the space requirements of the house, only minimum shelter planning standards need be considered. Since a family shelter can have a capacity of up to ten persons, the space requirements could represent five to ten percent of the house area.

First, the designer must decide if the shelter area is to serve only as a shelter or is to be used for other purposes as well. As dual purpose space, the shelter could be part of the utility area, the pantry, or a TV alcove. Where basement construction is feasible, single use space will be more economical.

Because of the rapid decay of the fallout material, it may not be necessary to spend the entire emergency period in a shelter area with a high protection factor, and the core concept should be considered. After a few days, short periods of time could be spent in areas with lower protection factors. Thus, if the shelter does not include all the necessities for a stay of two weeks, convenient access to these necessities should be planned without requiring passage through completely unprotected areas. If minimum space requirements are used for a highly protected area, adjacent spaces to this core with lower protection factors can be used to expand the shelter as the radiation intensity decreases. Adjacent outdoor areas could be partially decontaminated, further enlarging the size of the protected area.

Certain measures of habitability must be met to make a shelter usable. Shielding, floor space, and air are essential. Storage of water, food and supplies, sanitation, and power are also considerations that will influence the architectural design.

Utilizing the principles of shielding discussed earlier and using certain other planning rules will result in more economical shelter space. The more nearly the plan of the house approaches a square, the greater will be the geometry shielding. A long, thin plan would either require the shelter space to be located on an exterior wall or result in inefficient corridor space on both sides of the shelter. Irregular plans with courtyards result in penetration of contaminated areas into the plan form. A study of the house in section will quickly identify the ideal location for a shelter area. Any portion of a house below grade should be given first consideration. Openings into the shelter area which provide access, light, or ventilation should be baffled. Baffle arrangements may be used either in plan or section as illustrated in Figure 2-11.

The minimum space standards listed below, as established by OCD, are austere, but, used with the core concept, the minimum space could be used only for the highly protected area.



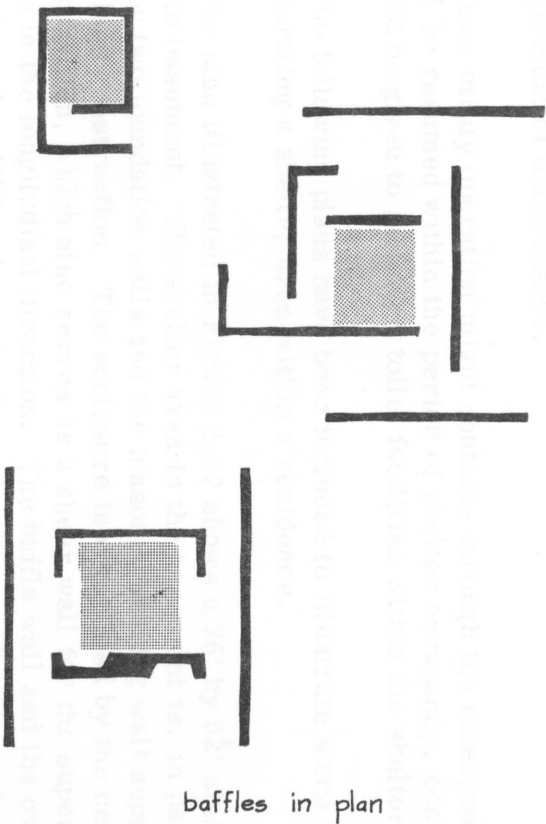
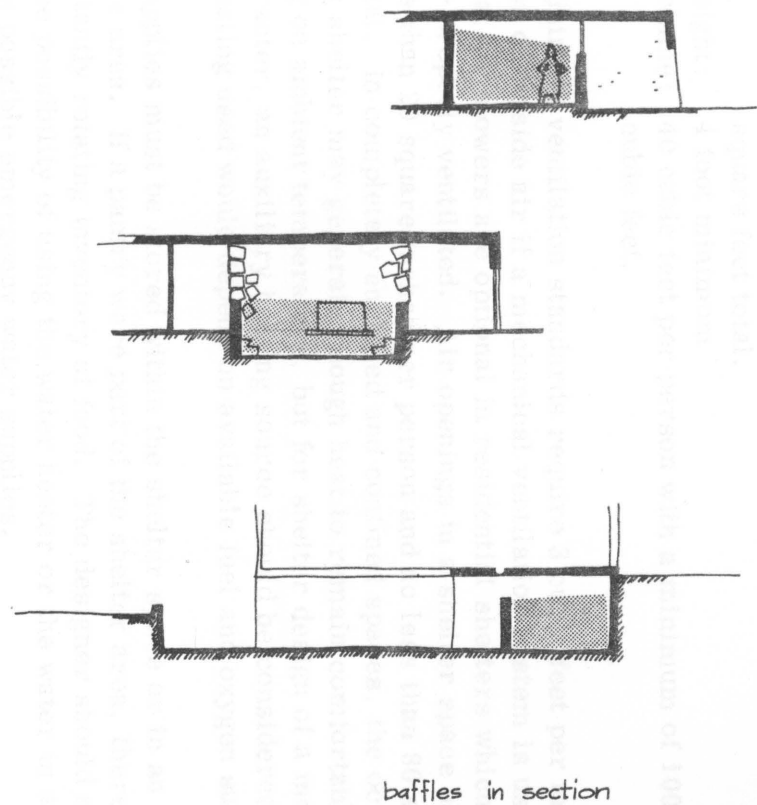


figure 2-11 baffle arrangements for shelter areas

Area: 10 square feet per person with a minimum of 25 square feet total.  
Height: 4 foot minimum  
Volume: 40 cubic feet per person with a minimum of 100 cubic feet.

Minimum ventilation standards require 3 cubic feet per minute per person of outside air if a mechanical ventilation system is used. Mechanical air blowers are optional in residential shelters which are otherwise properly ventilated. Air openings in a shelter space should be no less than 20 square inches per person and no less than 80 square inches total. In completely enclosed and confined spaces, the occupants of a shelter may generate enough heat to remain comfortable, depending on ambient temperature, but for shelter design of a more open character, an auxiliary heating source should be considered. The type of heating used would depend on available fuel and oxygen supplies.

Supplies must be stored within the shelter space or in an easily accessible area. If a pantry were part of the shelter area, there would be a constantly rotating inventory of food. The designer should not neglect the possibility of using the water heater or the water in a heating system as possible emergency water supplies.

When not in use, the shelter space should remain dry and clean with a minimum of maintenance.

Since utility operation might continue through the emergency period or be resumed within the period of shelter occupancy, consideration should be given to including toilet facilities within the sheltered area.

The following plans have been included to illustrate some examples of incorporating a shelter area within a residence.

The plan illustrated in Figure 2-12 shows a 26' by 52' single-story house with basement. The shelter area in the basement is, in part, defined by two foundation walls and the masonry bearing wall supporting the fireplace construction. The enclosure is completed by the center bearing partition, which also serves as a shear wall for the superstructure in the longitudinal direction. The baffle wall and the overhead slab are the only additional required construction. The concrete slab over the shelter also serves as a base for the tile flooring in the bathrooms.

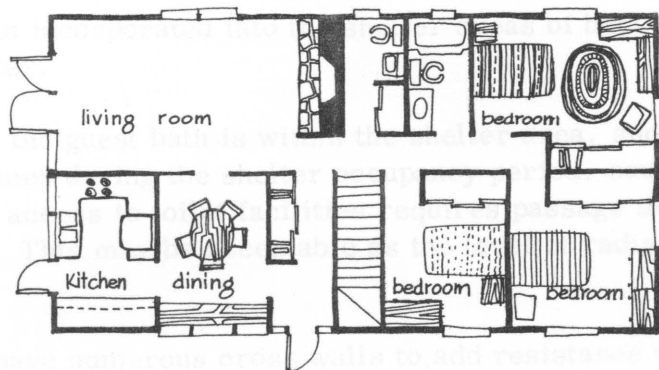
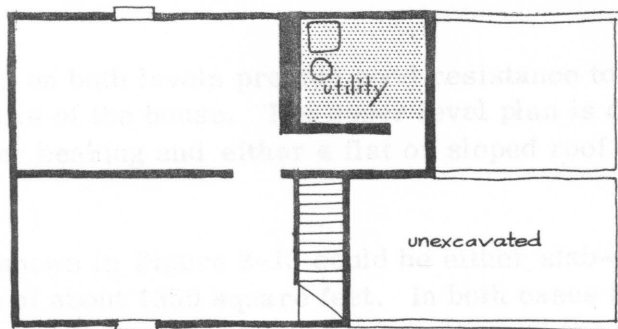


figure 2-12 house with shelter in basement

The water heater is in the sheltered area, providing an emergency drinking water supply.

The remainder of the basement has good protection, though not adequate to serve as a shelter in periods of heavy fallout unless a concrete slab is used for the entire first floor structure. After a few days, however, when the intensity of the radiation has diminished, short periods of time could be spent in the rest of the basement. The earth around the basement area should be banked up as high as possible to gain maximum shielding.

The cross walls on both levels provide good resistance to lateral loading for the long walls of the house. The upper level plan is designed with a continuous center bearing and either a flat or sloped roof could be used.

The two plans shown in Figure 2-13 could be either slab-on-grade or crawl space houses of about 1350 square feet. In both cases the utility room serves as the shelter area. The proportions of the plans require that one of the barrier walls be on the exterior.

In plan "a", the exposed walls of the shelter, both on the exterior and inside the residence, could be of brick, stone, or solid concrete masonry, providing an attractive finish material for the wall as well as excellent shielding.

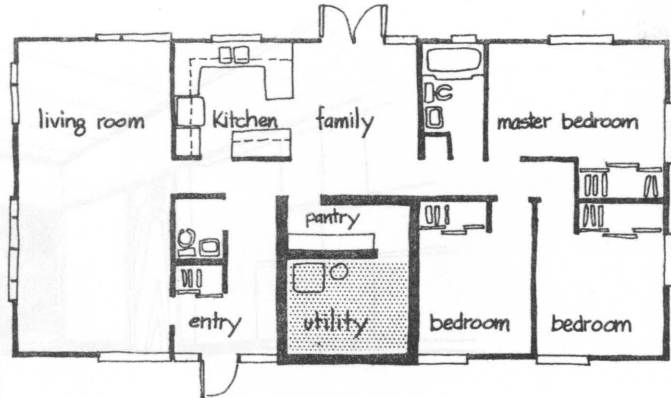
The pantry is incorporated into the shelter areas of both plans, as is the water heater.

In plan "b", the guest bath is within the shelter area, and, if water service resumes during the shelter occupancy period, could be used. In plan "a", access to toilet facilities requires passage through unprotected areas. This may be acceptable as the level of radiation diminishes.

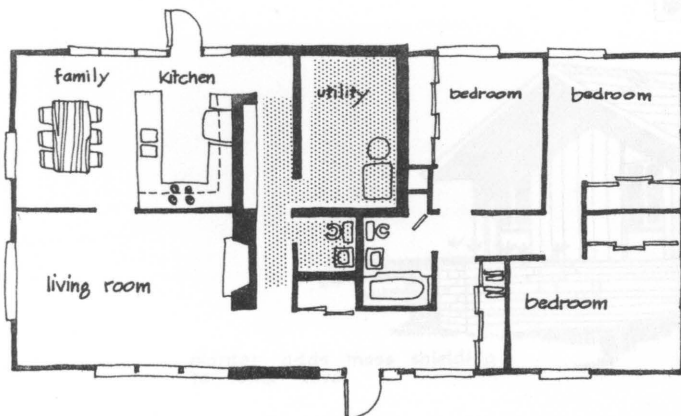
Both plans have numerous cross walls to add resistance to lateral loading on the long exterior walls. Plan "b" has a continuous bearing partition, which not only stabilizes the end walls but permits a choice of roof framing methods. In plan "a", where the center bearing does not continue through the living room, trussed rafters could be used.

The split-level scheme shown in Figure 2-14 illustrates how readily this plan type can be modified to include an excellent shelter area.

a



kitchen pantry within sheltered area



b

figure 2-13 one story plans with shelter



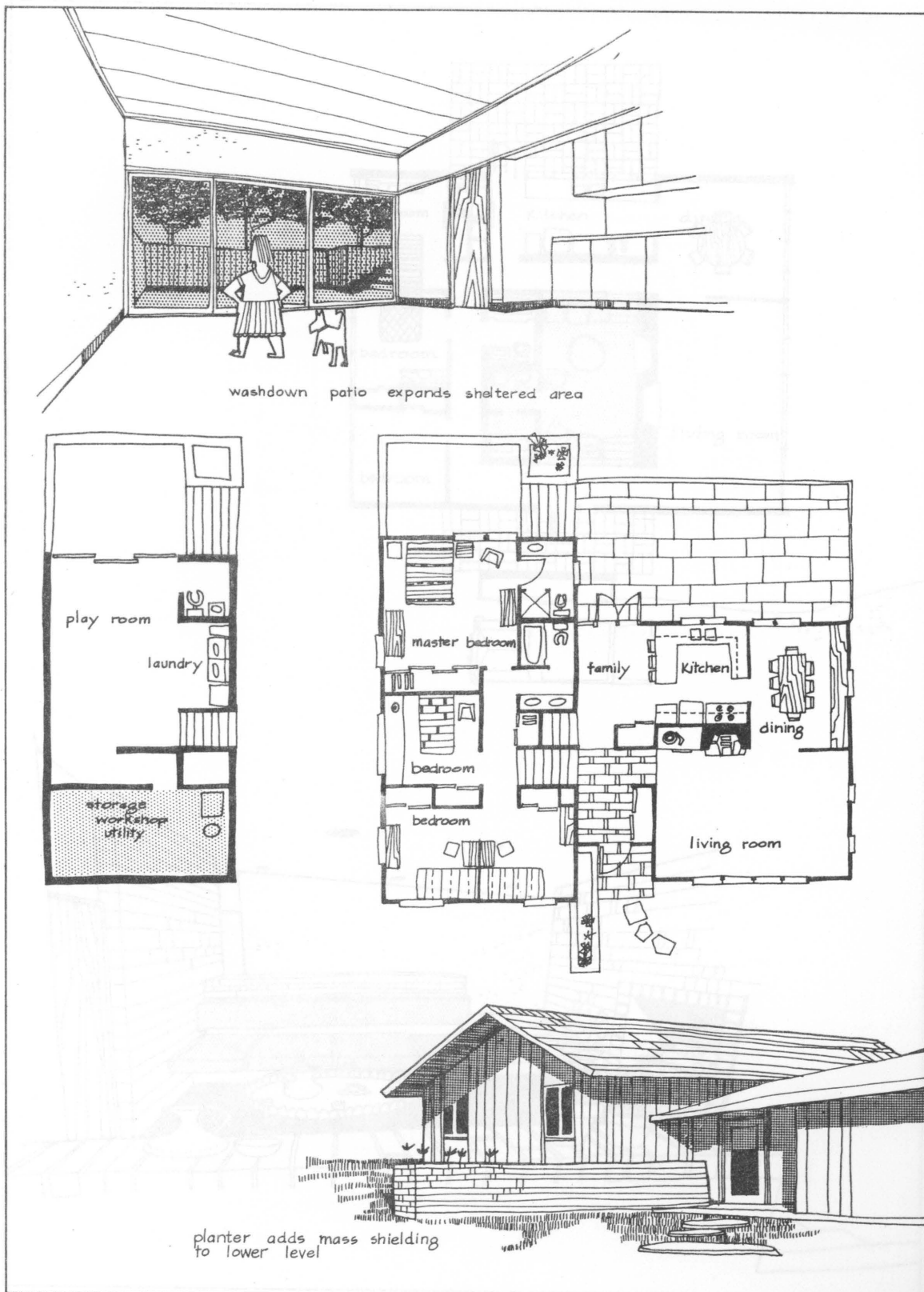


figure 2-14 split level house with shelter

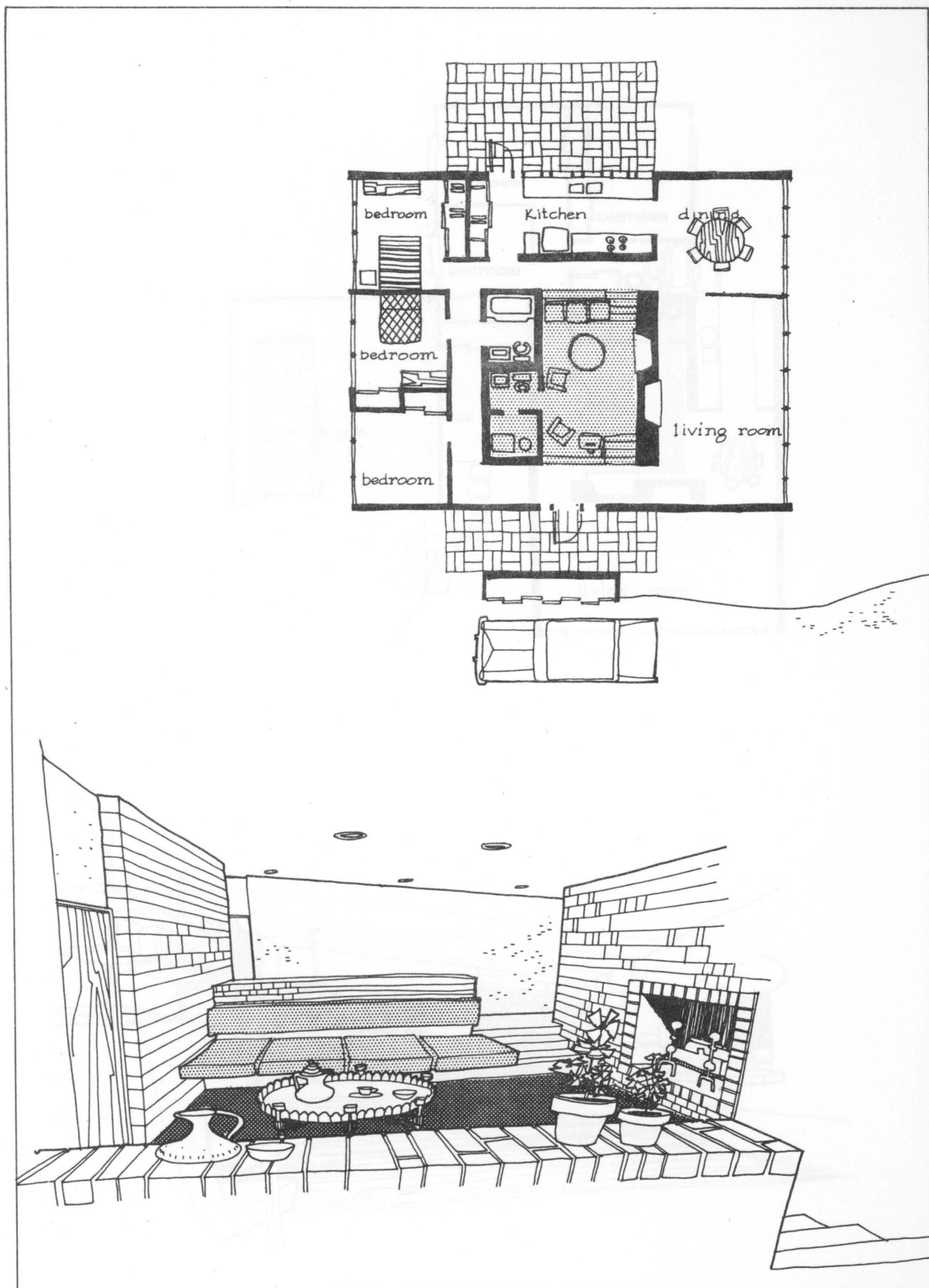


figure 2 - 15 shelter as part of living space

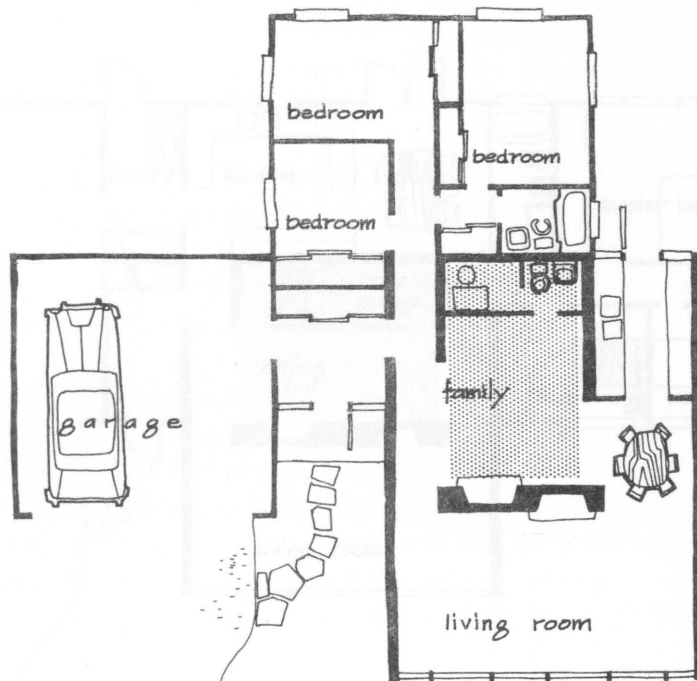


figure 2-16 shelter as part of the living area

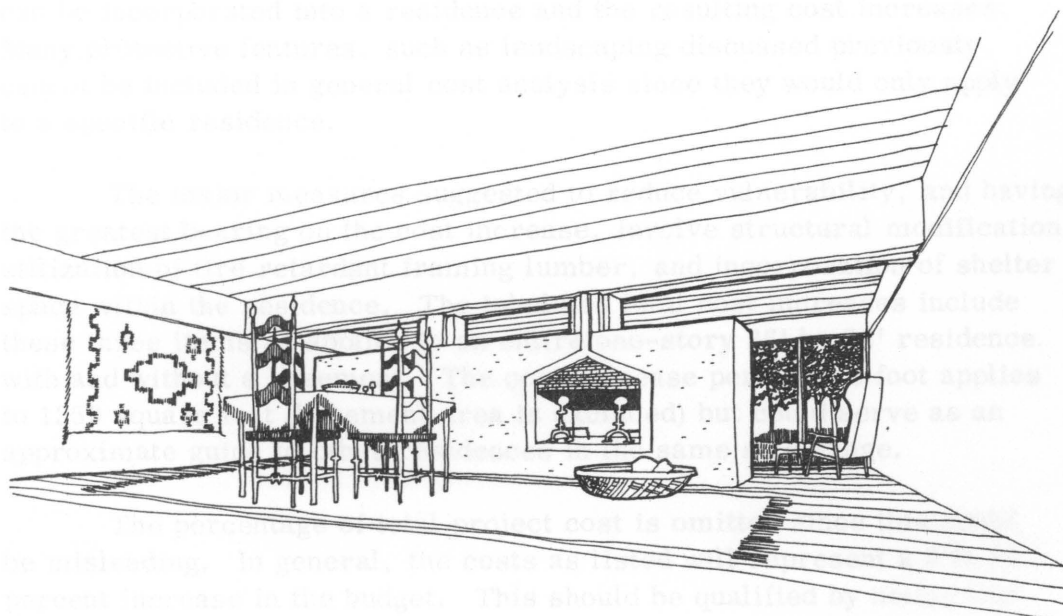
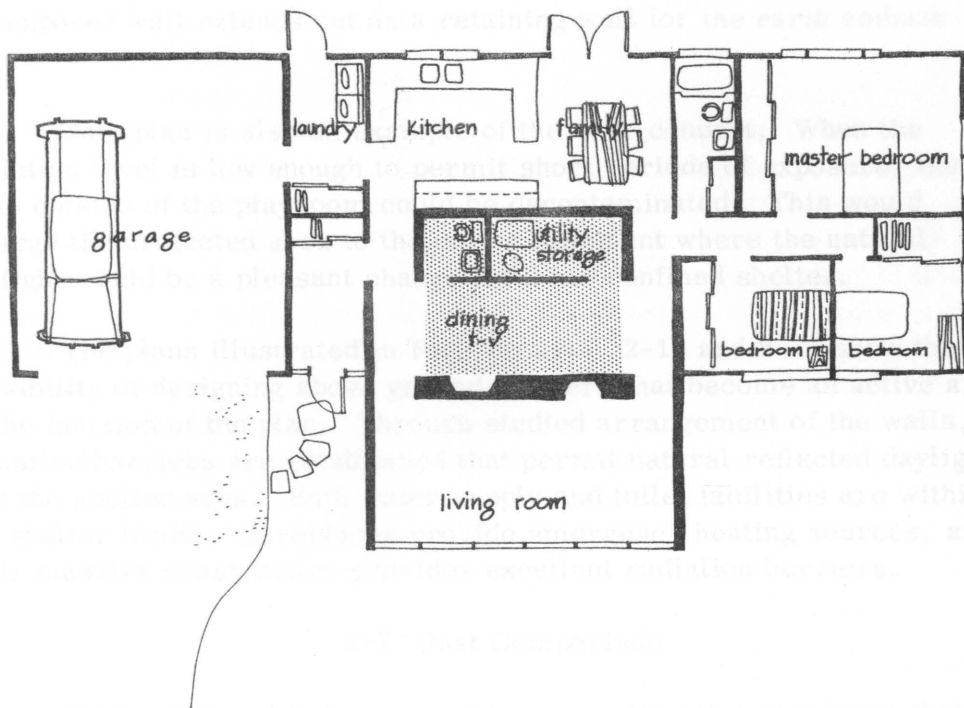


figure 2-17 shelter as part of living space

In the lower level, the shelter is enclosed by the addition of one barrier wall and an overhead slab. Earth around the shelter area is banked up for shielding. The planter which provides mass shielding on the remaining exposed wall extends out as a retaining wall for the earth embankment.

This plan is also an example of the core concept. When the radiation level is low enough to permit short periods of exposure, the patio outside of the playroom could be decontaminated. This would enlarge the protected area to the entire basement where the natural daylight would be a pleasant change from the confined shelter.

The plans illustrated in Figures 2-15, 2-16 and 2-17 show the possibility of designing above ground shelters that become an active area in the function of the plan. Through studied arrangement of the walls, radiation barriers are established that permit natural reflected daylight into the shelter area. Both water supply and toilet facilities are within the shelter limits. Fireplaces provide emergency heating sources, and their massive construction provides excellent radiation barriers.

## 2-7 Cost Comparison

Tables 2-3 and 2-4 summarize some protective measures that can be incorporated into a residence and the resulting cost increases. Many protective features, such as landscaping discussed previously, cannot be included in general cost analysis since they would only apply to a specific residence.

The major measures suggested to reduce vulnerability, and having the greatest bearing on the cost increase, involve structural modification, utilization of fire retardant framing lumber, and incorporation of shelter space within the residence. The tabulated total cost increases include these three items as applied to an entire one-story 26' by 52' residence, with and without a basement. The cost increase per square foot applies to 1350 square feet (basement area is excluded) but could serve as an approximate guide to other residences in the same size range.

The percentage of total project cost is omitted since this could be misleading. In general, the costs as listed will represent a 5 to 20 percent increase in the budget. This should be qualified by noting that it is not necessary to incorporate all of the features listed. One or more measures may be omitted, depending on the type of protection desired.



If emphasis is placed only on the structural strength of the house, the increase in cost per square foot ranges from about 30 cents to \$1.40. Total cost increase could be reduced by increasing the structural resistance of only a portion of the residence.

The strength factor is the ratio of the calculated level of failure of a strengthened residence compared with the calculated level of failure of a residence using minimum materials and connections currently acceptable. The outermost circle of Figure 2-18 represents the area of destruction of unstrengthened houses from a nuclear detonation. As the strength factors of the houses are increased, the areas of destruction will become progressively smaller. The percentage of decrease in area of destruction is noted on the circle of corresponding strength increase. As an example, 24% of the area within which a house would have been destroyed before strengthening could be considered safe if the calculated level of failure is increased 25% by corrective structural measure.

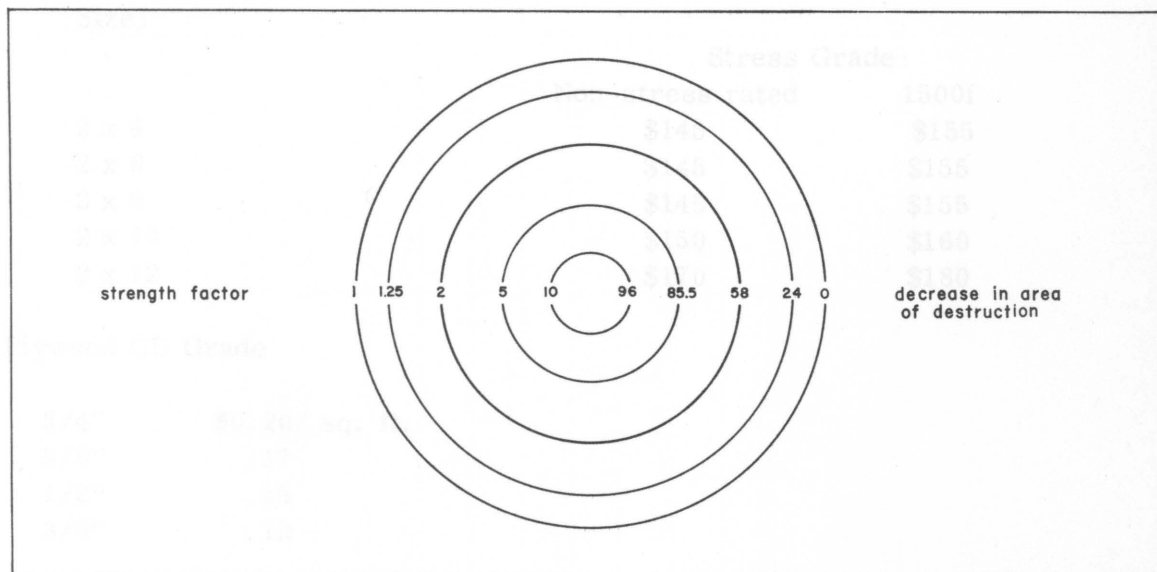


figure 2-18 comparison of strength factor with area of destruction

As the wall sections are increased in strength, the most economical floor and roof sections of corresponding strength are listed in the next columns.

The use of fire-retardant framing lumber represents a major initial cost. Since the strength of the house is directly related to the board feet of framing material used, the increased cost of fire-retardant wood increases rapidly with strength.

The shelter area cost is based on enclosing an eight-foot by ten-foot area. Above grade, a mass thickness of 200 pounds, using poured concrete, is assumed for the walls and the overhead barrier. The basement shelter is assumed to utilize two existing foundation walls. A mass thickness of 150 pounds is assumed on the remaining walls and 125 pounds for the overhead. Shelter types will vary, and these shelters were selected to illustrate average total protection costs.

The following material prices were used and should be adjusted for those areas of the country where there is wide variance:

Framing Lumber Size:	Cost per Thousand Board Feet:	
	Stress Grade:	
	Non-stress rated	1500f
2 x 4	\$145	\$155
2 x 6	\$145	\$155
2 x 8	\$145	\$155
2 x 10	\$150	\$160
2 x 12	\$170	\$180

#### Plywood CD Grade

3/4"	\$0.20/ sq. ft.
5/8"	.17
1/2"	.15
3/8"	.12

Pressure treated fire-retardant wood - Add \$90 per thousand board feet

Concrete: Formed walls - \$60/cu. yd.  
Formed slabs - \$50/cu. yd.

BALANCED STRUCTURAL PARTS				COST INCREASE (DOLLARS)															
Strength Factor	Wall Construction	Floor Construction	Roof Construction	Wall	Floor	Roof	Bearing Partition	Anchor Bolts	Improved Nailing	Fire Retardant Wood Slab House	Fire Retardant Wood Basement House	Shelter Above Grade	Shelter in Basement	Slab House		Basement House			
														Total	\$/sq.ft.	Total	\$/sq.ft.		
1.0	2 x 4 studs spaced 24" on center with 3/8" CD plywood sheathing	2 x 8 joists spaced 16" on center with 1/2" CD plywood subfloor	2 x 8 joists spaced 24" on center with 3/8" CD plywood sheathing																
MINIMUM REQUIREMENTS																			
2.0	2 x 4 @ 16 3/8 CD Glued	"	"	96	0	0	125	5	50	300	510	1400	550	1851	1.37	1336	.99		
2.5	2 x 6 @ 24 3/8 CD Glued	"	2 x 8 @ 16 1/2 CD	126	0	102	125	5	50	340	530	"	"	2023	1.49	1488	1.10		
2.6	2 x 4 @ 12 3/8 CD Glued	"	"	130	0	102	125	5	50	350	540	"	"	2037	1.51	1502	1.15		
4.0	2 x 6 @ 16 3/8 CD Glued	2 x 8 @ 16 1/2 CD Glued	2 x 8 @ 16 1/2 CD Glued	205	34	115	125	10	50	340	530	"	"	2120	1.57	1619	1.20		
4.8	2 x 6 @ 24 3/4 CD Glued	"	"	244	34	115	125	10	50	370	560	"	"	2189	1.62	1688	1.25		
5.2	2 x 6 @ 16 5/8 CD Glued	2 x 10 @ 16 1/2 CD	2 x 10 @ 16 1/2 CD	246	89	190	125	10	50	390	610	"	"	2286	1.69	1870	1.38		
5.4	2 x 6 @ 12 3/8 CD Glued	2 x 8 @ 12 1/2 CD Glued	2 x 8 @ 12 1/2 CD Glued	255	104	205	125	10	75	450	680	"	"	2395	1.77	2004	1.49		
6.4	2 x 6 @ 12 5/8 CD Glued	"	"	332	104	205	125	15	75	470	700	"	"	2497	1.84	2106	1.56		
6.6	2 x 6 @ 16 3/8 CD Both Sides Glued	"	"	375	104	205	125	15	75	440	680	"	"	2510	1.86	2129	1.65		
9.0	2 x 6 @ 12 3/8 CD int. Glued 5/8 CD ext.	2 x 10 @ 12 1/2 CD Glued	2 x 10 @ 12 1/2 CD Glued	480	191	278	125	20	75	550	810	"	"	2803	2.08	2529	1.87		
10.0	2 x 6 @ 12 3/4 CD Both Sides Glued	2 x 12 @ 12 1/2 CD Glued	2 x 12 @ 12 1/2 CD Glued	724	352	433	125	20	75	630	940	"	"	3282	2.43	3219	2.38		

Table 2-3 Cost Comparisons of 26' x 52' Residence with Flat Roof (Center Bearing)

BALANCED STRUCTURAL PARTS				COST INCREASE (DOLLARS)													
Strength Factor	Wall Construction	Floor Construction	Roof and Ceiling Construction 3/8" CD Plywood Roof Sheathing Used Throughout	Wall	Floor	Roof	Bearing Partition	Anchor Bolts	Improved Nailing	Fire Retardant Wood Slab House	Fire Retardant Wood Basement House	Shelter Above Grade	Shelter in Basement	Slab House		Basement House	
														Total	\$/sq.ft.	Total	\$/sq.ft.
1.0	2 x 4 @ 24 3/8 CD	2 x 8 @ 16 1/2" CD	Roof: 2 x 6 @ 16 Ceiling: 2 x 6 @ 16											MINIMUM REQUIREMENTS			
1.3	2 x 4 @ 24 3/8 CD Glued	"	"W" Truss @ 16" 2 x 4 Chords, 2 x 4 web	65	0	0	125	5	50	325	515	1400	550	1845	1.37	1310	.97
1.4	2 x 4 @ 16 3/8 CD	"	"W" Truss @ 24" 2 x 6 Chord 2 x 4 web	76	0	0	125	5	50	370	560	"	"	1901	1.41	1366	1.01
2.0	2 x 4 @ 16 3/8 CD Glued	"	"W" Truss @ 16" 2 x 6 Chords 2 x 4 web	95	0	135	125	5	50	390	575	"	"	2075	1.54	1535	1.14
2.6	2 x 4 @ 12 3/8 CD Glued	"	Modified Howe @ 16" 2 x 6 Chords 2 x 4 web	130	0	156	125	5	50	405	595	"	"	2146	1.59	1611	1.20
4.0	2 x 6 @ 16 3/8 CD Glued	2 x 8 @ 16 1/2 CD Glued	Roof: Conventional Rafters Ceiling: 2 x 8 @ 16 1/2" CD Glued	205	34	277	125	10	65	570	740	"	"	2527	1.87	2006	1.49
4.8	2 x 6 @ 24 3/4 CD Glued	"	"	244	34	277	125	10	65	575	765	"	"	2571	1.90	2070	1.53
5.2	2 x 6 @ 16 5/8 CD Glued	2 x 10 @ 16 1/2 CD	Roof: Conventional Rafters Ceiling: 2 x 10 @ 16 1/2 CD	247	89	323	125	10	65	595	810	"	"	2640	1.95	2219	1.57
5.4	2 x 6 @ 12 3/8 CD Glued	2 x 8 @ 12 1/2 CD Glued	Roof: Conventional Rafters Ceiling: 2 x 10 @ 16 1/2 CD Glued	255	104	326	125	10	65	650	840	"	"	2706	2.05	2275	1.69
6.4	2 x 6 @ 12 5/8 CD Glued	"	"	332	104	326	125	15	65	665	855	"	"	2803	2.08	2372	1.75
6.6	2 x 6 @ 16 3/8 CD Both Sides Glued	"	"	375	104	326	125	15	65	640	825	"	"	2821	2.10	2385	1.77
9.0	2 x 6 @ 12 3/8 CD int. 5/8 CD ext. Glued	2 x 10 @ 12 1/2 CD Glued	Roof: Conventional Rafter Ceiling: 2 x 10 @ 16 1/2 CD Both Sides Glued	479	191	544	125	20	65	780	1040	"	"	3288	2.44	3014	2.24
10.0	2 x 6 @ 12 3/4 CD Glued Both Sides	2 x 12 @ 12 1/2 CD Glued	"	724	352	544	125	20	65	820	1250	1400	550	3573	2.65	3630	2.69

Table 2-4 Cost Comparisons of 26' x 52' Residence with 4/12 Sloped Roof

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